MODERN BUILDING CONSTRUCTION

MODERN BUILDING CONSTRUCTION

A COMPREHENSIVE, PRACTICAL, AND AUTHORITATIVE GUIDE
FOR ALL ENGAGED IN THE BUILDING INDUSTRY

Edited by

RICHARD GREENHALGH
A.I.Struct.E.

ASSISTED BY MANY SPECIALIST
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MODERN BUILDING CONSTRUCTION

THE TRAINING AND OPPORTUNITIES OF AN ARCHITECTURAL STUDENT

By THOMAS E. SCOTT, F.R.I.B.A., HON.F.I.B.D.

THE successful practice of architecture probably demands a greater degree of individual ability, versatility, and hard work than any other profession, but to those who possess the requisite skill, patience and industry, it can offer the enviable satisfaction of a career which is both useful and pleasurable. It is one which contributes to the success of almost every form of human existence.

Most of those who incline towards architecture as a career do so in the first instance because of a natural aptitude for drawing; this aptitude is usually reflected in artistic interests, but rarely does the novice appreciate the many sides of the profession he has entered. He eventually discovers that architecture, although essentially an art, involves also a wide knowledge of technical matters and business acumen of a high order. Whatever the qualifications and experiences of those who created the architectural masterpieces of past ages, the architect of to-day will find that artistic skill and imaginative genius alone will not suffice; the realization of his schemes will call for and depend upon wide knowledge and the discriminating use of an extraordinary range of materials, and the ability to satisfy the complicated and exacting needs of contemporary civilization.

Personal Qualifications. A gift for drawing, then, is an accepted qualification, but it must be accompanied by natural interest in colour, form, and those qualities which are indefinable but which generally distinguish the beautiful from the commonplace or ugly. Artistic ability is a gift which only nature can bestow, but if it exists, it can be trained and developed towards that process of artistic analysis, selection and arrangement which may be called Design. But as this process of design is related to the consideration of material and practical requirements, so it will call for powers of inventiveness and ingenuity in the manipulation of planning forms and constructional details. There must be an instinctive desire to create and construct, for that is the true function of the architect. Finally, it is not sufficient for him to have an understanding of the materials of construction only, for the buildings of to-day require also a wide range of mechanical and other equipment for which proper provision must be made at the planning stage if efficiency is to be combined with aesthetic quality.

Pre-professional Education. Much has been said and written about the general education of intending architects, but the selection of architecture as a career is usually made when it is too late to vary the course of school studies. Perhaps this is as well, for a sound liberal education is the surest foundation for all careers, and it is frequently the case that the acquisition of an education on broad lines enables a student to discover his otherwise hidden talents, and so make a choice which is both happy, profitable and wise. Up to the School Certificate stage it is desirable, within reason, to study those subjects for which one has a natural inclination, since it is in these subjects that success is most likely to be found. Most students are likely to leave school after passing the School Certificate or Matriculation examination, either of which will constitute the entrance qualification to a school of architecture and for Probationership of the Royal Institute of British Architects. Those who are able and elect to remain at school for a further period may find an opportunity of studying those subjects which will form a more specialized background for subsequent technical studies. Such subjects as applied mathematics, chemistry and physics are undoubtedly useful, but it is questionable whether they will prove to have a more lasting and beneficial effect than a study of the classics. As an alternative, a period spent in a good art school may afford an invaluable opportunity of gaining a sympathetic appreciation of the kindred arts. There is no hard and fast rule, and so long as general

education has reached a satisfactory standard any further education may well follow natural aptitudes and avoid specialization.

Study of Architecture. The scope of architectural training must be related to the wide field of knowledge upon which the architect in practice must of necessity draw. But as no architect can expect or be expected to have a profound knowledge of every aspect of planning, construction and equipment to be encountered in modern buildings, so a student need not—indeed he cannot—study exhaustively every subject of the curriculum. His training, however provided, should aim at the systematic study of basic principles, a thorough understanding of which will enable him to continue his professional education by means of practical experience in whatever capacity he may find himself, and to co-operate intelligently with those specialists with whom he will ultimately be associated in practice.

The subjects of the curriculum which are briefly outlined may to some extent be studied separately, but at all stages they must be regarded as inter-dependent, finally to be merged and united in that process called *design*.

Design. Architectural design is more than mere draughtsmanship: it is a process of selection and composition which has for its objective the creation of fine buildings, expressive of and appropriate to their respective purposes, and structurally sound. Thus, the study of Design is in effect the study of the many matters which may affect the planning, construction and equipment of buildings, preceded, perhaps, by some development of natural ability in drawing and instruction in the technique of architectural draughtsmanship, in order that creative conceptions may be recorded and presented. There are no hard and fast rules of design, but as explained elsewhere in this volume, the critical study of buildings may reveal certain dimensional and other characteristics which are common to many works of merit. Such creative, inventive and artistic ability as a student may possess must be developed by this critical study, and by systematic exercises in the working out of problems of design. Such development will inevitably be influenced by the study of fine buildings, both historical and contemporary. Mere copyism is to be discouraged, as is a vain desire to be original at all costs. The architect who has studied widely and has sought to understand the manner in which fine architecture has been achieved is most likely to be able to approach his own problems successfully. Too frequently the young student limits his own powers of design by restricting his studies to a narrow and prejudiced field of research: he fails to realize that although many works of past ages have points of detail and planning which are no longer appropriate, they may also have certain qualities of design which, if sympathetically studied, cannot but stimulate and broaden his own work. The successful study of design must be carried out under the guidance of an experienced and sympathetic teacher, whose analytical and constructive criticisms of design exercises will not of necessity force the student to conform to his own outlook, but will enable him to develop *his own* individual ability. There are many excellent books on the principles of planning and composition, the study of which can never reveal any *rules* of design, but by encouraging the truly critical examination of buildings will indirectly develop the creative powers of design.

Draughtsmanship. It has already been assumed that some ability in drawing is one of the chief reasons for choosing architecture as a career. This ability must be developed as the medium by means of which the architect records his work and conveys his instructions to others.

Freehand drawing, descriptive geometry, shades and shadows, perspective, rendering and lettering should be studied and practised in order that designs may be adequately illustrated at all stages in their development, and finally recorded as working drawings in a clear concise and accurate manner which leaves no doubt of the architect's intentions. A drawing worth making is worth making well, but fine draughtsmanship is not an end in itself. It ought rather to be regarded as the language of the architect, by which means alone he can secure the co-operation of the craftsmen and others who translate his conceptions into buildings.

Construction. The study of architectural construction should include the properties and uses of all materials in general use, details of their application to building problems, and the principles and practice of design of structural members. It is usually convenient for these to be taught and studied separately, but there should always be that cross-reference which their inter-dependence requires.

The range of materials to be studied should be as wide as modern building practice, but the student rarely needs to acquire more than a

general knowledge of properties and characteristics in relation to normal use, standards of quality and size, methods of fixing and assembly, and relative costs. It is an advantage to have an understanding of the physical and chemical laws which control the behaviour of certain materials, particularly cements and plasters, but the average architect has neither the time to acquire nor the opportunity to use an expert knowledge of these matters; scientific problems involving laboratory work and research must be left to specialists.

The study of constructional details—normally referred to as "building construction"—should include those traditional crafts which are still in general use, and also the whole range of present-day mechanical and other processes, including prefabrication. Knowledge of construction must be founded on an understanding of the principles involved and not merely on memorized typical details. Constructional details should be studied as they are created, that is, as solutions to a particular problem in which the structural, aesthetic and other requirements have been given due consideration. The student should make frequent visits to buildings in course of erection and to builders' workshops, where materials and craft processes will assume a reality which cannot be imparted by lecture or textbook.

The extent to which an architect may advance his knowledge of Structural Design must depend upon his individual capacity and the nature of his practice, but as a general rule, he ought to be able to deal effectively with those problems which are encountered in everyday practice. To this end, and with an adequate background of mathematics and mechanics, the student should acquire a knowledge of the basic principles of all ordinary forms of construction, and of the application of standard formulae to the solution of problems. His knowledge should be adjusted from time to time to take account of the results of research, but unless he intends to embark upon a career as an engineering specialist he may well limit his studies to those aspects of structural design which he is likely to practise sufficiently to remain proficient.

History and Theory of Architecture. The history of the art of architecture should be studied for what it is—the story of the development of civilization as recorded by buildings. It is natural that some notice should be taken of styles, names, places and dates, a knowledge of which may give conviction and realism to a conversation or an examination paper, but the real value of the study of this fascinating subject will result only from a realization that the buildings of all ages reflect contemporary life and customs and geographical conditions, in the same way that similar factors will influence those of our own age. If properly undertaken, the study of historical architecture will include the study of those other arts and crafts which have in the past and will in the future continue to contribute so much to the decoration and furnishing of buildings. It is perhaps well to point out that although examinations do not normally involve a knowledge of the history of architecture after the end of the eighteenth century, a student may with considerable advantage study the work of the nineteenth and twentieth centuries, both at home and abroad. Such study may reveal the reasons for many more or less recent tendencies in design, and that which might otherwise be regarded as a fashion or decorative invention may be found to have a close relation to structural or other conditions.

The "theory" of architecture refers, generally, to those principles of design which form the basis of architectural analysis and criticism. The subject may be studied from works dating from the time of Vitruvius up to the present day; in them are to be found a variety of philosophies on the arts, analyses of architectural form and principles of composition and planning. As has already been stated, design is not controlled by rules but rather by the exercise of personal judgment and artistic instinct: these are essentially natural qualities which cannot be endowed by instruction, but *where they exist* can be developed and stimulated by a constant inquiry into the reason for beauty in its many forms.

Building Services and Equipment. The architect needs a working knowledge of the many service installations required in modern building. Here, as in so many branches of architectural practice, the student cannot expect to acquire a full and detailed knowledge of every subject, but he should make himself familiar with the basic principles and methods of practice so that he can make adequate provision for the services at all stages in the development of a design, and collaborate intelligently with the specialists whose works are involved. His knowledge should enable him to deal independently with the requirements of buildings of a normal character where it is not usual to employ the services of a consulting engineer, and in particular,

the ability to discuss problems with clerks of works, foremen and craftsmen will enhance his own reputation and secure the best possible results on the site, where much of the most important and valuable work of the architect is, or should be, performed.

The following are the most important of the many subjects to be studied: plumbing, drainage and sanitation; sewage and refuse disposal; water supply, heating, ventilating and air-conditioning systems; natural and artificial lighting; acoustics, and the various forms of electrical and other mechanical equipment in common use.

Professional Practice and Office Routine. Thus far, the subjects of the curriculum are related to the production of designs and working drawings, but there remain those other subjects which are concerned with the translation of those drawings into structure. These include Land Surveying, Specifications, a general understanding of the nature and objects of a Bill of Quantities, and methods of Estimating. In addition, the architect must have a proper appreciation of his responsibilities, powers and duties in his relations with Clients, Quantity Surveyors and Consultants, Adjoining Owners, Local and other Authorities, and with the Contractors and their employees. He should be aware of the standards of professional conduct and the relation between the Scale of Fees and the services he renders to his clients, and of the whole business procedure of negotiating with all parties concerned with the erection of his buildings. As a student, he will not expect to do more than gain a knowledge of the rules, regulations and customs which govern these matters, but as soon as he enters the office of an architect he will find opportunities of learning how the business of architectural practice is carried on. And unless these affairs are conducted in an efficient manner to the ultimate and reasonable satisfaction of those with whom the architect is associated in his business, whether in a private or official capacity, his technical and artistic training may count for nothing.

Town and Country Planning. A large proportion of the building work of the future is likely to be controlled to some extent by planning legislation, and it is therefore important that every architect should have some knowledge of the history, law and practice of urban and rural planning, but the scope of the architect's normal work is so wide that the student should not attempt more than this general survey until after he has become qualified. Should he then desire to specialize in this sphere the subject should be fully studied in its many aspects of design and administration.

Systems of Training

There are two general forms of preparation for and entry into the architectural profession: Full-time training in a school of architecture, and office pupilage with part-time study.

Schools. The most important schools of architecture are those recognized by the Royal Institute of British Architects. These schools all provide a three-years' full-time course up to the Intermediate stage, and most of them also offer a further Final course extending over approximately two years. The successful completion of these courses may qualify for exemption from the Intermediate and Final Examinations respectively. The instruction given covers the requirements of those examinations, and by close collaboration between the R.I.B.A. Board of Architectural Education and the Schools it is ensured that a satisfactory standard is maintained. Each school, however, has its own special characteristics, and it may fairly be stated that the keen and capable student will far exceed the standard of knowledge and competence required by the examinations. Success in the examinations held at the end of the Final courses is also a qualification for registration under the Architects' (Registration) Acts.

There is a growing tendency for students to complete the full Final course before entering offices, and many of those who begin their studies in an Intermediate school proceed to a Final school for the Final stage. There are now so many scholarships and free places available at the various schools that those possessing the necessary degree of natural ability should have little difficulty in qualifying in this way for entry to the profession. At the same time, some may prefer to enter offices as junior assistants on the completion of an Intermediate course, and to study for the Final Examination in an evening school or privately. Such an arrangement may offer certain advantages, particularly if the student is fortunate enough to enter an office where he can gain experience on a variety of good class work, but it is questionable whether those advantages outweigh those of studying systematically the more advanced subjects of the curriculum and of developing his powers of design under conditions which even the best of offices can never offer.

During the longer vacations, and during part of the fifth year, the full-time student is expected to work in an architect's office or on building works in order to gain experience in the realities of practice. At the same time, the Final student ought not to consider himself fully equipped to engage in private practice immediately he has completed his school training. Success in modern architectural practice involves more than artistic skill and theoretical knowledge; it depends to a considerable extent upon the manner in which the architect conducts the affairs of his clients, and negotiates with contractors and others during the whole process of translating his client's wishes into completed structures. Indeed, the Associateship of the Royal Institute of British Architects is not conferred until after a prescribed period of time has been spent in gaining practical experience and business training.

Pupilage. Few architects are now able or willing to accept articled pupils. Indeed, it is doubtful whether the conditions of architectural practice will ever again afford those leisurely opportunities for intimate relationship between principal and pupil which in the past have made this form of training practicable, and which are essential if a young man is to gain an adequate knowledge of his profession by this means. In some parts of the country remote from the schools and having perhaps no satisfactory facilities for part-time or evening study, some form of pupilage may be the only means of training, but such districts are few and are likely to require a less highly technical knowledge and skill of local practitioners than the bigger industrial towns and districts.

At the same time, the architectural profession is likely to continue to call for the services of a number of assistants in very junior capacities, and given suitable qualifications, young men filling these posts may find opportunities of gaining useful experience in drawing office practice. If this experience is supplemented by careful and systematic training in a good evening school, the assistant may ultimately be able to pass the R.I.B.A. examinations, and become properly qualified. The way is long and tedious, and except in specially favourable circumstances is unlikely to provide the high degree of skill and range of technical knowledge needed in present-day practice. But in spite of any difficulties, it must be the ultimate aim of all who enter the ranks of the profession to become properly qualified members; in fact the law is such that only those who are so qualified and registered can describe themselves as architects.

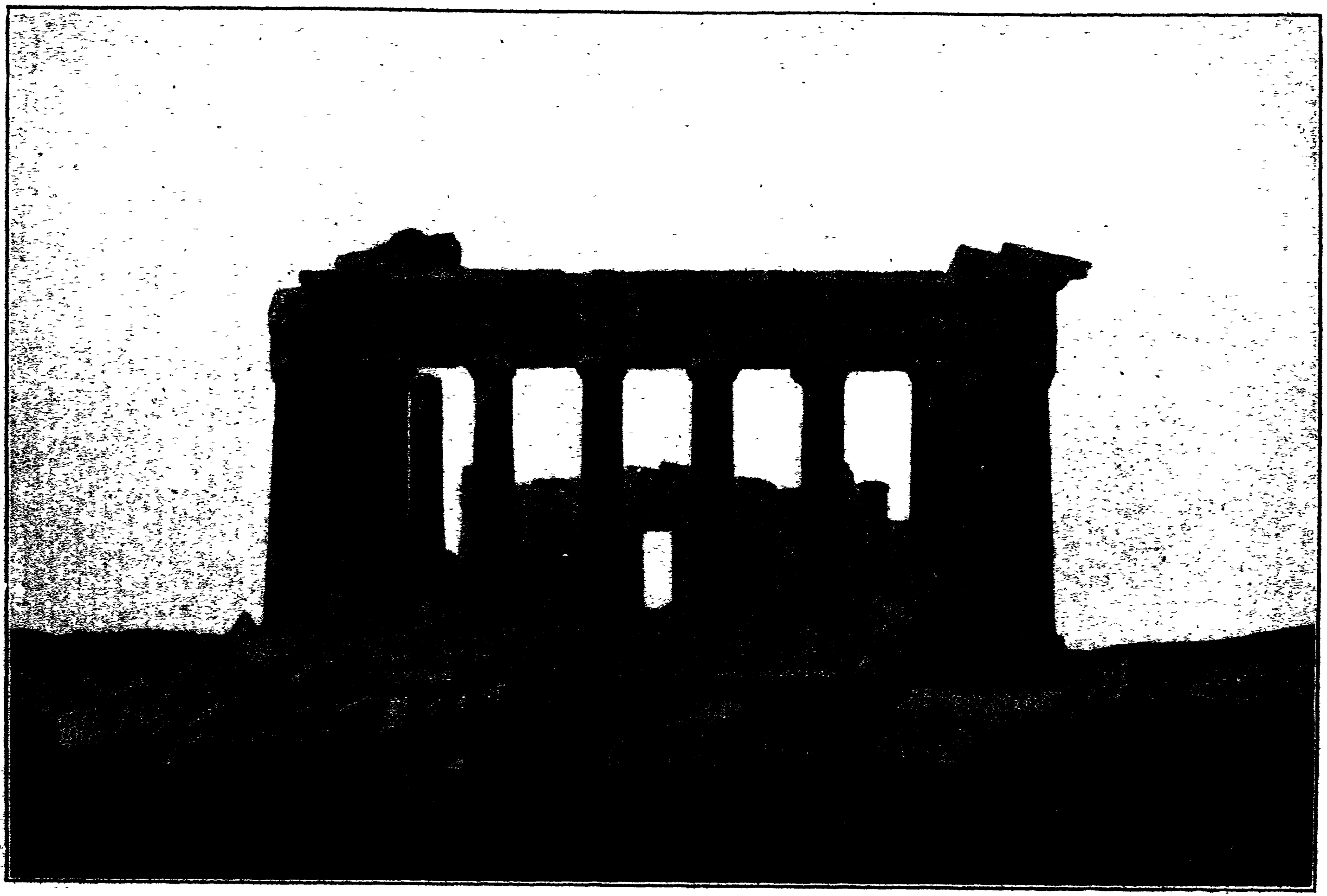
EXAMINATIONS. The statutory qualification for architects is registration under the Architects' (Registration) Acts after passing one of the approved examinations. These examinations include the Final examinations of the R.I.B.A., and the Final examinations conducted by those schools which have been approved by the Architects' Registration Council of the United Kingdom. The requirements of those examinations are covered by the outline curriculum already indicated; full details can be obtained on application to the Royal Institute of British Architects at 66 Portland Place, London, W.1.

Opportunities

The architect may exercise his skill in a variety of ways, according to his ability, temperament or opportunities. He may practise, either independently or in partnership, dealing with work of a general character or specializing in particular types of building such as hospitals, schools, or housing. He may function as a salaried official, either under a central or local government authority, or for a commercial or other organization. But not all architects can hope to practise as principals, whether private or official, and many fully qualified men and women will find secure, profitable and interesting employment as senior assistants. Indeed, the tendency for municipal and other authorities to appoint properly qualified architects to their staffs is increasing, and it is likely that such architects will be largely responsible for the design of buildings needed to provide for the ever-increasing programmes of education and social welfare, etc.

Few architects are able at the outset to establish themselves in private practice, and even if this were possible, it is always highly desirable to spend a considerable time in the office of an experienced man in order to gain a knowledge of ways and means of running an office, and of dealing with clients, contractors, local authorities and others concerned with the carrying out of building works.

The future would appear to offer great opportunities, and many will be encouraged to contemplate careers in architecture by the popular interest in re-building schemes to provide for housing, education, social service, and almost every form of national life.



By courtesy of the R.I.B.A.

ATHENS: THE PARTHENON, FROM THE EAST

From the Drawing by R. Phene Spiers, Esq., F.R.I.B.A., F.S.A.

History of Architecture

By THOMAS E. SCOTT, F.R.I.B.A., HON.F.I.B.D.
Head of the Department of Architecture, Northern Polytechnic, London

Chapter I—THE ORIGIN OF ARCHITECTURE

IN all ages, buildings have been created to satisfy the needs of human beings—their shelter, work, religions, and pleasures. It will usually be found that the outlook of the people is evidenced in the care bestowed upon the buildings most important to their civilization.

The importance of religion and power of the priesthood accounts for the great number of temples built by the Egyptians, while their expectation of the return of the soul to its former body some 3,000 years after death explains the massive, eternal nature of their tombs. The Greeks, with their simple customs, and desire for the ideal for its own sake rather than the pretentious, had few material requirements, and were content to concentrate on the perfection of an accepted form of temple. The Romans, however, appear to have possessed a national temperament akin to that of nations of the present day: ambitious, commercial, and with a love of grandeur and pleasure, it is obvious that they required a great variety of buildings for their work and amusement. How natural that such a nation should have little time for religion! Roman temples, although probably plentiful in the days when Rome was in its prime, were not nearly as magnificent as the public and other buildings. And later, when Christianity had spread over Western Europe, it is found that the influence and power of the Church resulted in a great enthusiasm for church building to the exclusion of almost all other works. In the past, as well as the present, the very essence of the life of a nation is expressed in its architecture.

It is most useful and interesting, in the study of historic architecture, to investigate the relationship between *structure* and *architectural form*; to observe, in the early buildings in the two great styles—CLASSIC and GOTHIC—the limitations of constructibility controlling the creation of buildings, and later, through added knowledge and experience, the subservience of construction to the expression of ideals. In the examination of Greek work, it will be found that buildings were almost standardized in general form owing to the limitations of the lintel, or beam, form of construction, and that later, the introduction of the arch and the use of concrete by the Romans permitted an almost infinite variety in architectural form; in many cases, in fact, the art of construction was so mastered, that it was hidden in the provision of the enrichment so adored by the Romans. The development of architecture from the twelfth to the fifteenth century, both in England and the rest of Western Europe, is an excellent illustration of the evolution of a style in which construction and decoration progressed side by side, the form of the various features being invariably determined by structural necessity, subsequent enrichment beautifying them, but never hiding the constructional function. It will be interesting to compare the heaviness and timidity of the early Norman work (Fig. 2) with the decision and delicacy of the later Gothic period (Fig. 3). By the comparison of such examples, and by the careful analysis of the buildings of the past, it is possible to appreciate the magnitude of the many constructional problems which confronted their builders.

It is not within the scope of this treatise to consider in detail the development of the various features which have been used in the architecture of the past, but it is essential to their logical application to the design of modern buildings that their structural origin is understood.

The influences of climate will be evident as the various styles are dealt with; however commonplace these influences may seem, they are important factors which must not be overlooked.

Although these more material considerations of utility, construction, and climate have affected

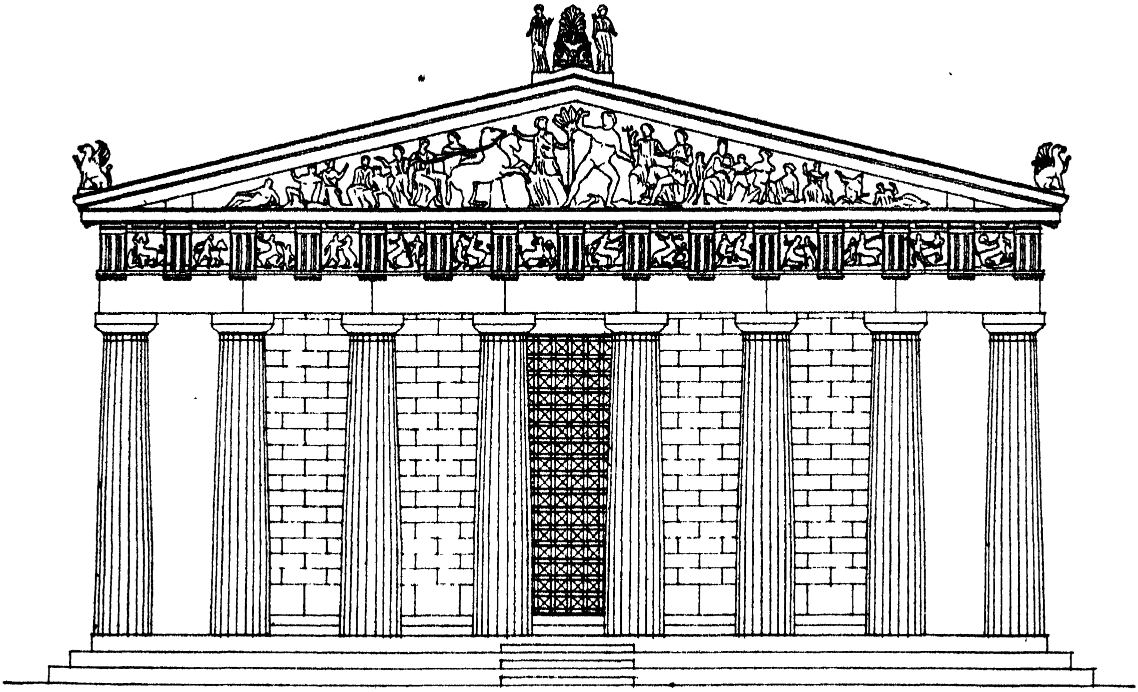


FIG. 1. THE PARTHENON, ATHENS

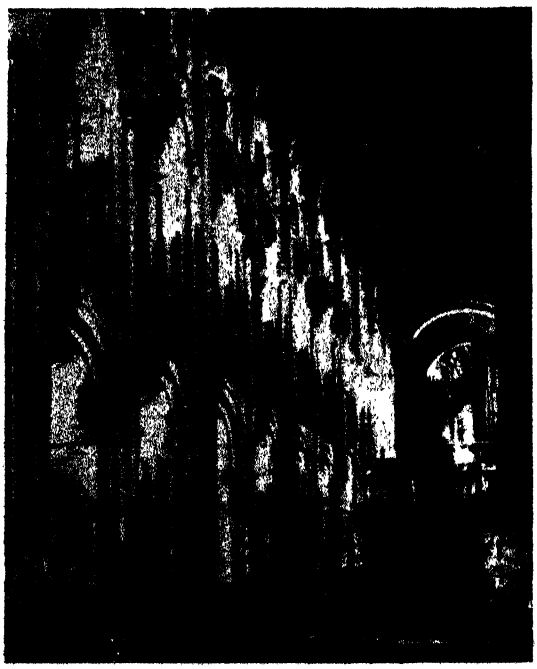


FIG. 2. THE NORMAN NAVE, NORWICH CATHEDRAL

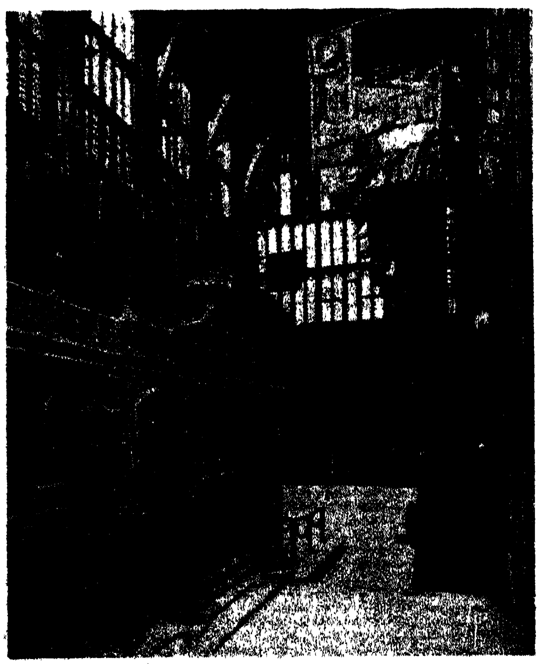


FIG. 3. HENRY VII'S CHAPEL, WESTMINSTER ABBEY

the general form of buildings, it was the constant striving after effect that gave character to the architecture of the past. It was the infusion of a nation's temperament into its buildings that imbued them with a character which history shows to be the crystallization of contemporary civilization: the mystery and expression of eternity in Egyptian temples and monuments (Fig. 4); the refinement and simplicity of Greek work (Fig. 1); the grandeur and power of the Roman baths, Basilicas, and other great buildings (Fig. 5); and so, as the great epochs of the past are reviewed, the temperament of the people is found to be indelibly written in their buildings.

Although, for convenience, the history of the architecture of the past is subdivided into *periods*, or *styles*, it is necessary to remember that evolution has been continuous; changes occurring, not as a result of the passing fancies of the builders, but as the outcome of the constant advance and spread of civilization

FIG. 4. TEMPLE OF HORUS, EDFU

through the various national and social happenings in the world's history.

There were periods of transition when architecture was of a hybrid nature; when buildings, while retaining the essence of a decadent style, displayed certain minor features, usually decorative, culled from some fresh source which travel or literature had opened up. Subsequently, the better understanding of these new ideas led to their development into a style expressive of local ideals and requirements, and modified to suit local materials and labour. And so the evolution of architecture proceeded throughout the ages, reflecting always the great events which have brought nations together in peace and war, and the great social, industrial, and religious movements which have produced civilization as it is to-day.

To appreciate architecture to the full, it is

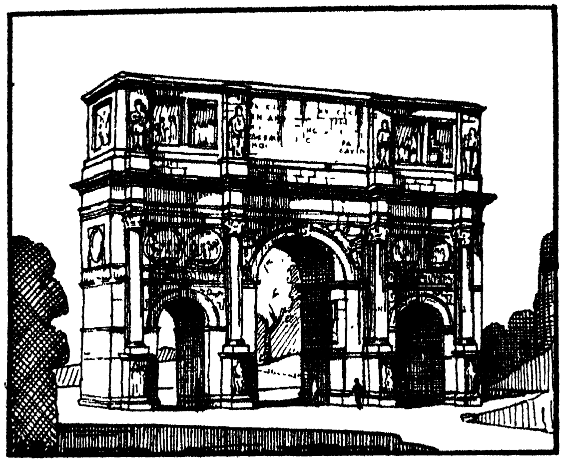


FIG. 5. THE ARCH OF CONSTANTINE, ROME

necessary to recreate mentally the conditions which produced it: to visualize the life and customs which existed when the buildings of the past were in their full glory, for it is only when its human quality is appreciated that architecture becomes a real part of civilization, instead of a mass of technicalities.

EARLIEST ARCHITECTURE

Egypt. The earliest civilization of which there is any reliable information is that of Egypt. Its history is derived from the Scriptures, from Greek and Roman writers and from its buildings; through the latter it may be traced back to about 4,000 years B.C., and even at that early date there is evidence that the Egyptians were possessed of great constructional ability.

The remains of Egyptian architecture suggest that the chief buildings were temples and tombs, and the substantial way in which they were built is expressive of the importance of religion and the power of the priesthood. The Egyptian appears to have regarded life as a transitory existence, anticipating that his soul, after death, would sojourn for 3,000 years with *Osiris*, or in

the body of an "unclean" animal, according to the judgment of the deities, ultimately returning to its former body. Not only was the body most carefully embalmed for preservation, but colossal tombs were erected for its protection, and for the storage of certain worldly possessions against the return of the soul. How well this was done is evident from recent discoveries by the late Lord Carnarvon and Mr. Howard Carter.

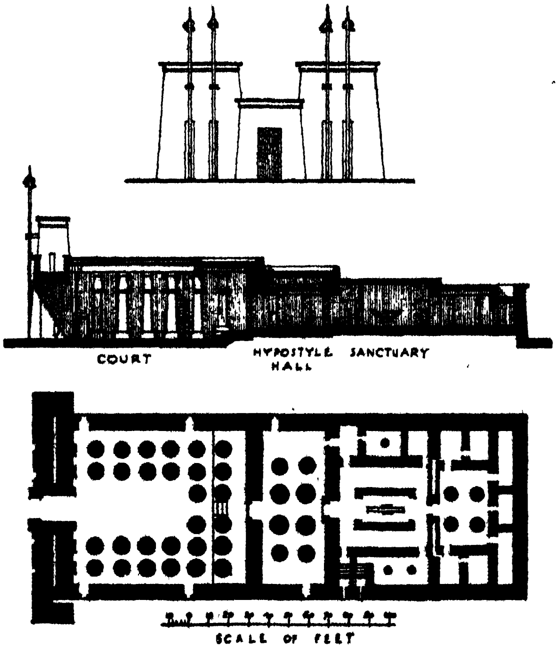


FIG. 6. THE TEMPLE OF KHONS, KARNAK
Front Elevation, Section and Plan

Of domestic buildings, there are no remains of any account; this is natural, not only because of the relative unimportance of earthly life on religious grounds, but also on account of the nomadic existence necessary in hot climates.

TEMPLES. The temples were jealously guarded sanctuaries, which only the king and priests might enter. They were vast structures, created to impress, and suggestive of the mystery of the rites and processions which took place within. The Temple of Khons, Karnak (Fig. 6), built about 1200 B.C., is a characteristic example. It will be appreciated that the raising of the floor levels and lowering of the roof increased the appearance of size, the forest of columns gradually fading away in the almost black darkness of the unlit interior.

TOMBS. There were three general types of tomb.

The *Pyramids*, familiar in form to all, were built by the kings to contain their preserved bodies. The Great Pyramid of Cheops, 3733 B.C., was a gigantic undertaking; it is about 756 ft. square and 482 ft. high, and the accuracy of workmanship in its erection is astounding. Some of the blocks of stone weigh as much as fifty tons, and yet they were fitted with great exactitude, and in the lengths of the sides there is a variation of only 1·7 in. Even with the vast amount of slave labour available, it is almost impossible to realize how so stupendous a task was carried out.

The *Mastabas* were small structures, used as tombs for less important personages. In later periods, tombs were usually cut into the face of the rock, an entrance giving access to an underground corridor which led to the various chambers. At Beni-Hasan there is a remarkable group of tombs, built between 2500 B.C. and 2200 B.C., the entrance to one of which (Fig. 7)

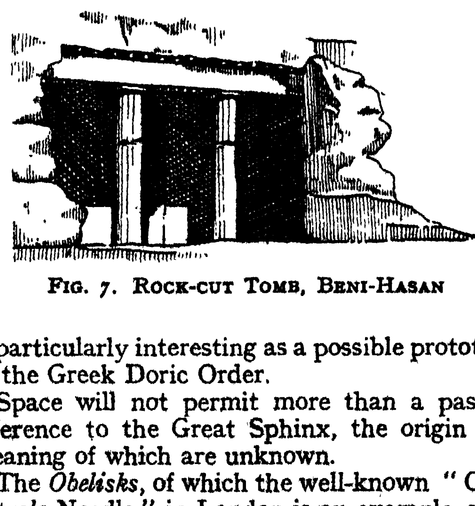


FIG. 7. ROCK-CUT TOMB, BENI-HASAN

is particularly interesting as a possible prototype of the Greek Doric Order.

Space will not permit more than a passing reference to the Great Sphinx, the origin and meaning of which are unknown.

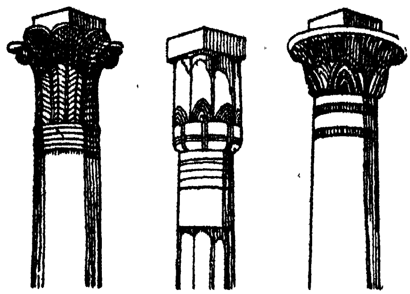
The *Obelisks*, of which the well-known "Cleopatra's Needle" in London is an example, were decorative pillars which stood in pairs at the entrance to temples. Their quarrying, transport, and erection are interesting subjects for speculation.

CRAFTSMANSHIP AND MATERIALS. The abundance of unskilled slave labour is a factor which has contributed largely to the massive character of Egyptian buildings, but it was the organization and engineering skill of the Egyptians which made such works possible.

The materials used were granite, sandstone, limestone, and sun-dried bricks; timber, although available in small sizes, was not generally used for the temples, but was possibly employed

in the building of houses. Alabaster was used as a decorative material.

ARCHITECTURAL CHARACTER. It is highly probable that a mud and reed form of building, practised on the banks of the Nile, was the prototype of the stone architecture which followed. Walls were immensely thick, usually battered or sloped on the outer face, and, when built of stone, were frequently decorated with carving and hieroglyphics, the latter contributing very largely to our knowledge of Egyptian history.



A B C

FIG. 8. EGYPTIAN CAPITALS

(A) Palm Leaf Capital. (B) Lotus Bud Capital. (C) Bell, or Lotus Flower, Capital

Walls of brick, and sometimes those of stone, were plastered, both as a protection against the weather and to provide a suitable surface for colour decoration. This was applied in the form of a low relief sculpture, the process probably consisting of the drawing of the figures by an artist, their outlines cut, and the forms slightly modelled by a sculptor, and the whole finally coloured by the painter. Colour decoration was used internally, where, owing to the subdued light, it was necessary that the colours should be strong and bright, red, blue, and yellow being most frequently used. The reader is referred to the *Grammar of Ornament*, by Owen Jones, for some excellent illustrations in colour of Egyptian and many other types of decoration.

Window openings were rare, light being admitted over dwarf walls between columns (Fig. 4).

Roofs were flat, consisting of slabs of stone supported by the walls, and massive, closely spaced columns (see Fig. 6). The decoration of these columns appears to have been evolved from the bundles of reeds, of which the earliest buildings were probably constructed. The treatment of the upper parts of the columns, known as capitals, was inspired by local plant life, such as the lotus bud and flower, and the papyrus, the former being the symbol of fertility (Figs. 8A, B, and C).

Beams consisted of plain stones, sometimes surmounted by a simple moulding (Fig. 9A).

Ornament was usually simple, consisting of symbolical features, such as the sacred beetle, or scarab, the globe and vulture, which was a symbol of protection, and diaper patterns and running bands of various types (Fig. 9).

Egyptian architecture, although occupying no very important place in the history of the arts, must always be recognized as one of the finest evidences of the expression, in building, of the life story of a nation. It should be studied too, for its massiveness, eternal nature, strength, and mystery—qualities in the expression of which it has never been excelled.

Western Asia. Little now remains of the architecture of the nations who ruled the countries of Western Asia; but there is sufficient evidence to show that the Greeks were, to some extent, influenced by the works they found there. Histories usually refer to three styles—Chaldean, Assyrian, and Persian—but there is little vital difference between them, although they all differ greatly from Egyptian work.

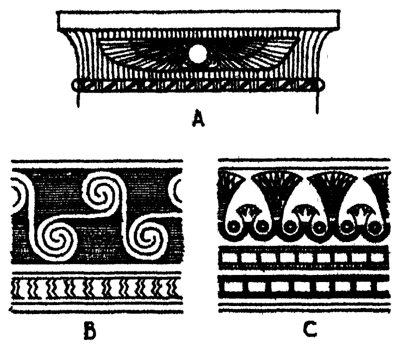


FIG. 9. EGYPTIAN ORNAMENT

(A) "Gorge" moulding, with feather ornament and winged solar disc. (B) Spiral ornament. (C) Frieze with lotus motif

The scarcity of stone and timber led to the use of sun-dried bricks, and buildings lacked the durability of those of the Egyptians; and thus little remains of the magnificent palaces which excavations show to have existed.

The architecture of the Persians, at one time rulers of Western Asia, attained great magnificence, and the vast Hall of Xerxes at Persepolis, the capital, was undoubtedly one of the largest and most imposing buildings of antiquity. There exist now, however, only the vast platforms and terraces of rock (natural precautions against floods) upon which these palaces were built.

Chapter II—GREEK ARCHITECTURE

ALTHOUGH Greek architecture did not emerge from its archaic or primitive state until about the seventh century B.C., the few remains of the earlier works are interesting, for they must be accepted as the foundation upon which European architecture was built.

The earliest known inhabitants of Greece were the Pelasgi, but it seems probable that the civilization which produced the great works, which will be described later, at first developed in Crete, an island to the south of Greece.

Explorations reveal a marvellous civilization which existed in Crete over four thousand years ago; space will not permit an adequate description of the achievements of these early people, but the high degree of their civilization is illustrated by the fact that, at the palace at Knossos, there existed a drainage system which was not equalled in Europe from that day until the nineteenth century.

Cretan settlements were established on the mainland at Mycenae and Tiryns, the former of which gives the name of "Mycenaean" to this early Greek architecture.

Mycenaean Period. This period is usually considered to last until the eighth century B.C. The remains found in many parts of the country are chiefly of town walls, fortifications, and tombs. The chief feature of the work is the use of massive blocks of stone, which were built in their rough state or hewn into rectangular blocks and bonded together; mortar was not generally used. This masonry is called "Cyclopean," tradition ascribing its origin to the legendary giants, the Cyclopes.

At Mycenae, the town wall contains the famous Gate of Lions (Fig. 11), the carved panel over which is probably the earliest example of Greek sculpture remaining.

Perhaps the oldest existing Greek structure of architectural importance is the Treasury of Atreus at Mycenae; this was undoubtedly built as a tomb. Although the large chamber is shaped like a dome (Fig. 12), it is not constructed as such, but consists of overhanging courses laid horizontally. This chamber is about 50 ft. broad and 50 ft. high; the great size of the stones used in its erection will be appreciated when it is said that the lintel over one of the doorways is 27 ft. long and 16 ft. deep, and weighs over 100 tons. It is interesting to note over this lintel the corbelling which forms a triangular opening, and thus relieves the lintel of the weight of the wall over. A similar arrangement is to be seen in Fig. 11, in which case the opening is filled with the carved panel.

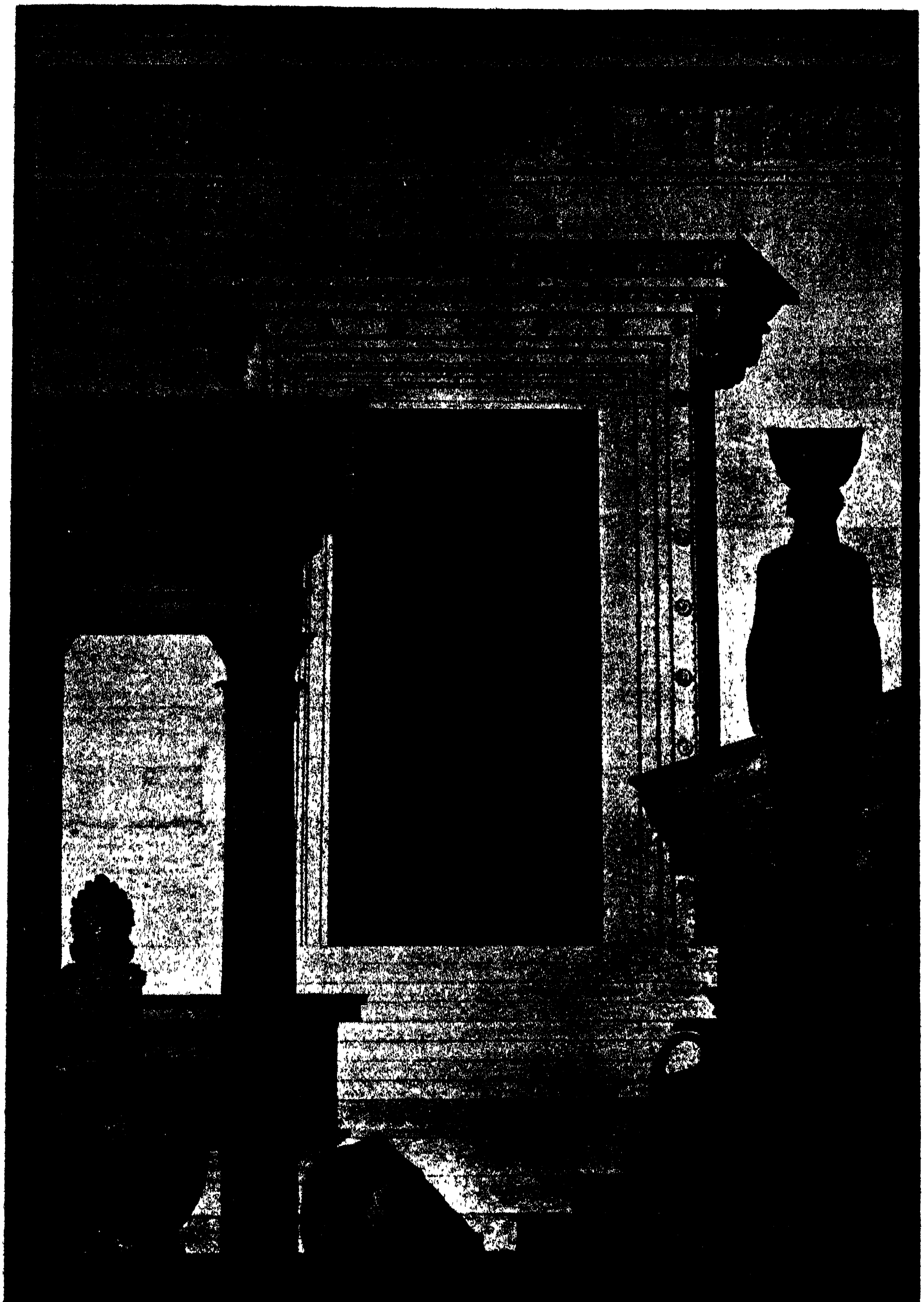
Hellenic Period. The mature architecture of the later period differs greatly from the early works of the Greeks. There are not sufficient remains to enable its evolution to be followed with any certainty, but it is possible to trace the factors which undoubtedly influenced its development during the centuries which intervened between the Mycenaean and Hellenic periods.

The study of a map of the Mediterranean Sea will show that the position of Greece was such that contact with Egypt and Asia was inevitable. The Greeks came into touch with Egypt through commerce, and were doubtless influenced by the columns used there; it is quite possible that the fluted column of the Doric Order was inspired by columns at the rock-cut tombs at Beni-Hasan, already referred to. The Greeks were great colonists and established settlements as far afield as Asia Minor. In this way they became acquainted with the buildings of the Assyrians and Persians, from which they acquired a love of rich detail.

Although the Greeks appear to have been influenced by the work of other countries, their architecture rarely contains mere copies of foreign details, but rather an intelligent application of carefully selected features, which have been refined by their wonderful feeling for delicacy and proportion.

Many races are known to have settled in Greece during the early centuries; the resulting people, known as the Hellenes, were never a united nation, but rather a group of self-governing states, drawn together by a passion for athletic games, religious festivals, and a love of fine arts, the drama, and music.

The history of Greece during the Hellenic period, known as the Golden Age, is well told by historians; it may be said to begin with the commencement of the Olympiads, 776 B.C., and to end with the sacking of Corinth by the Romans during the second century B.C., although



From a drawing executed in the School of Architecture, Northern Polytechnic, London

FIG. 10. A COMPOSITION OF ELEMENTS OF GREEK ARCHITECTURE

Background, a doorway from the Erechtheion. Foreground, *Right*, a Pediment, a Caryatide. *Left*, the "Order" from the Tower of Winds

Greek architecture was continued with more or less purity for some time afterwards. Outstanding events were the defeats of the invading

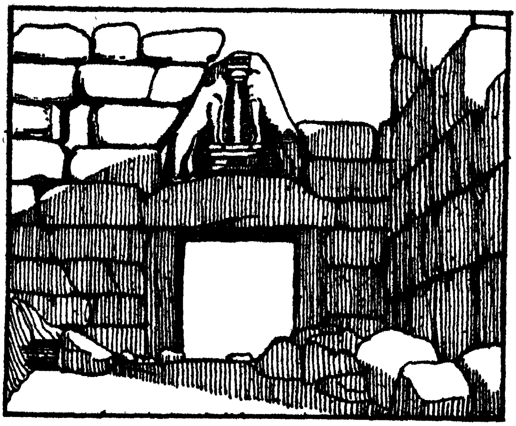


FIG. 11. THE LION GATE, MYCENAE

Persians on land at Marathon in 490 B.C., and on the sea at the battle of Salamis in 480 B.C. These victories were followed by a period of

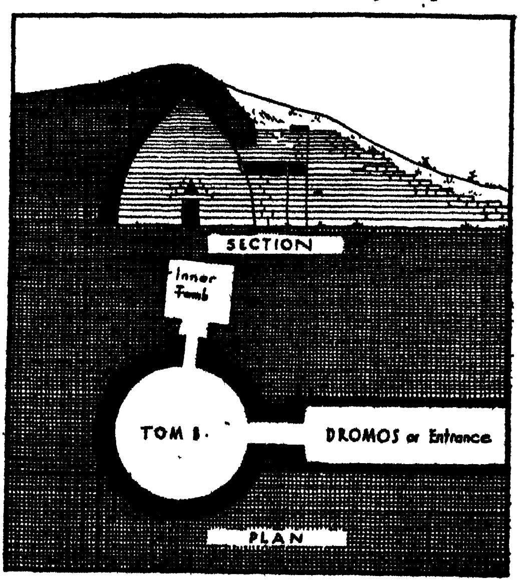


FIG. 12. THE TOMB, OR TREASURY, OF ATREUS MYCENAE

great prosperity, which produced the finest buildings of the Greeks. Temples and public buildings were rebuilt on a scale far surpassing those which had existed previously, and new temples were erected in thanksgiving to the local deities. A period of decline ensued, to be followed by a short revival under Alexander the Great.

Temples. The climate of Greece permitted an outdoor life which influenced the arrangement of their buildings. Both religious and civil ceremonies were usually carried on in the open air, so that the effect aimed at was usually an external one.

The Greek religion consisted chiefly of the worship of deities which personified certain qualities, such as Athena, the Goddess of

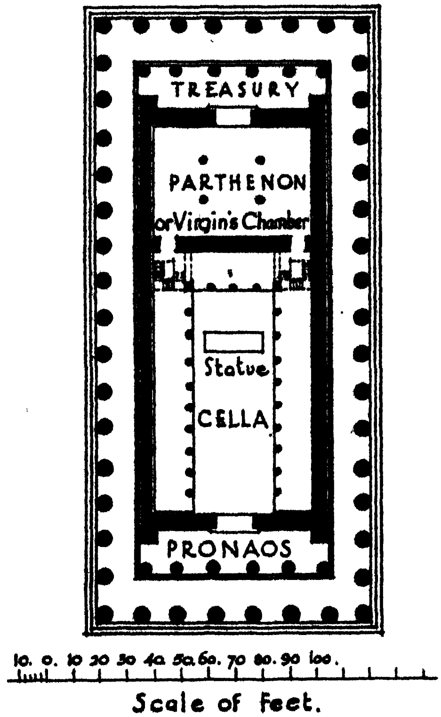


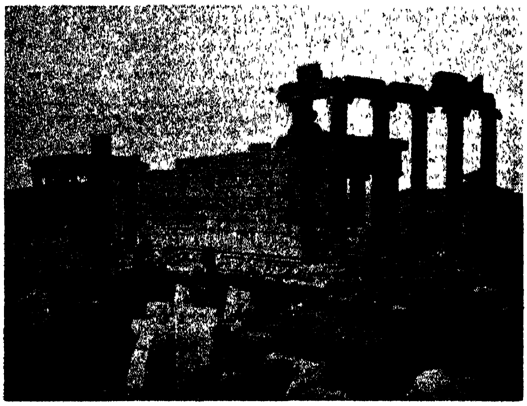
FIG. 13. PLAN OF THE PARTHENON, ATHENS

Wisdom, and Hercules, the God of Power. Each district had its own deities.

The temples were built as shrines to contain the images of the gods, rather than as places of assembly for the people, who offered their prayers from any point in sight of the temple. For this reason, the temple, together with smaller shrines and other buildings connected with religion, were frequently grouped together in a prominent place. Sometimes a part of the city was set apart as sacred; that at Athens, known as the Acropolis, or Upper City, is perhaps the best known. There is a very good model of it in the British Museum.

The temples were usually very simple in plan, containing a rectangular apartment for the image, called the *Naos*, and a colonnaded

portico, called the *Pro-naos*. Some temples also contained a chamber behind the *Naos* which was used as a store for treasures; and in larger buildings columns were ranged all round, forming an ambulatory or covered corridor. The whole stood upon a platform, and was covered by a simple roof with a gable at each end.



R.I.B A. Gates Collection

FIG. 14. THE ERECHTHEION, ATHENS FROM THE S.E.

The absence of windows leads to much speculation as to the lighting of these temples. It seems probable that a system of clerestory lighting was used, and also top-lighting through an opening in the roof. Many of the temples were so placed that the morning sun might enter the door and light up the statue opposite.

The finest of the temples was the Parthenon, at Athens, dedicated to the Goddess Athene. It was built during the years 454–438 B.C. in the time of Pericles, one of the greatest rulers in Greece; the architects were Ictinus and Calicrates. The plan (Fig. 13) was quite simple, consisting of a sacred chamber and a small treasury behind it, with a portico at each end. Round these was a range of columns, called a *peristyle*, eight at each end and seventeen on each side. These columns were a little over 34 ft. high, and had a diameter at the base of 6 ft. 3 in. They supported an entablature 11 ft. high, which, at the ends, was taken up in the form of a gable, known as a pediment (Fig. 1). The main chamber, or cella, was divided into a nave and aisles by columns, whose chief function was to support the roof; there were also four columns in the treasury for the same purpose. The architectural treatment of the columns and entablature will be referred to later. Near the western end of the *Naos* was placed the statue of the Goddess *Athene Parthenos*, one of the most wonderful works of Phideas, the celebrated Greek sculptor. It was constructed of ivory, and covered in places with plates of solid gold; including its base, it was about 40 ft. high. The illustration of the Parthenon shows the positions of the sculpture on the elevations; there was also a very fine sculptured frieze on the outside of the cella walls.

Another small but very fine temple was the Erechtheion (Fig. 14), situated near the Parthenon on the Acropolis. The reason for its irregular plan (Fig. 15) is a matter for conjecture, though there may be some connection between the three porticoes and the three deities whose shrines it contained. The porticoes are of different designs, two being of the Ionic order, which will be described later, and the third a *caryatid* portico, consisting of six draped female figures standing upon a wall and supporting an entablature of rather unusual design; a restoration of one of the *caryatides* is to be seen in Fig. 10. The doorway illustrated in Figs. 10 and 16 is one of the finest examples.

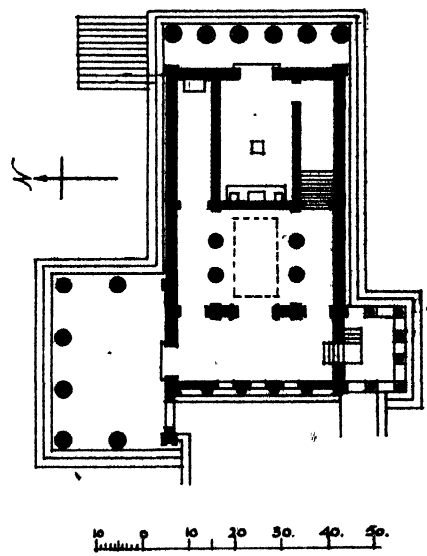


FIG. 15. PLAN OF THE ERECHTHEION, ATHENS

The remains of the secular work of the Greeks are very scarce. One of the best known is the monument of Lysicrates at Athens (Fig. 17), erected in 335 B.C., in commemoration of his success in the choral competitions. It was a circular structure with a square base, in all just

over 20 ft. in height. Around the upper part were six half columns, with capitals known as Corinthian, a type not common in Greek work.

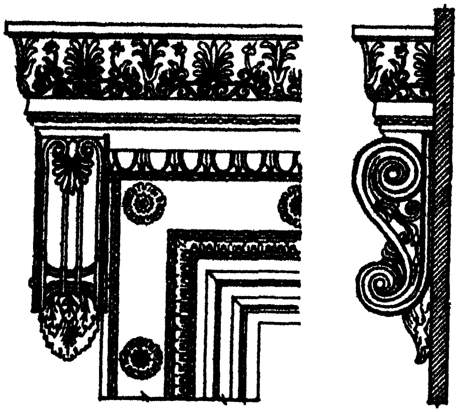


FIG. 16. DOORWAY, THE ERECHTHEION, ATHENS
Details of the Console, Architrave and Cornice

The entablature and a finely enriched crowning part were formed from one slab of marble.

The burial places of the dead were usually marked by a simple form of tombstone known

R.I.B.A., Gates Collection

FIG. 17. CHORAGIC MONUMENT OF LYCICRATES, ATHENS

as a *stele*, somewhat similar in form to the modern variety. A number of large monuments are known to have existed, one of the finest of which was probably the Mausoleum at Halicarnassos, in Asia Minor. Although it is not definitely known what this monument was like, remains suggest that there was a square plinth or base supporting a number of Ionic columns, with a fine sculptured group forming an important feature. It is believed to have been about 140 ft. high, and is ranked as one of the seven wonders of the world. Many very interesting fragments, and a drawing of a conjectural restoration, are to be seen at the British Museum.

Theatres appear to have been very important in Greek life. Dramatic performances were looked upon as festivals, in which every inhabitant of the district took part. The theatres were usually hollowed out of a convenient hillside and, as will be seen from Fig. 18, were rather more than a semicircle on plan, with a central space for the chorus and a narrow stage for the actor or actors. The auditorium was cut

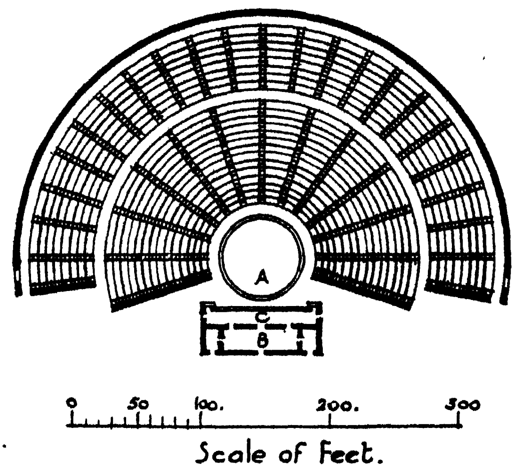


FIG. 18. PLAN OF THE THEATRE AT EPIDAUROS

A. Orchestra *B*. *Skene*, or dressing rooms *C*. *Proskenion*, or stage

out of the solid rock, with tiers of marble seats. In the Theatre of Dionysos at Athens, over thirty thousand people could be accommodated.

Agora, or market-places, were large open spaces surrounded probably by colonnades, and around them were grouped various public buildings, many of which were used for the athletic performances, which were so important a feature of Greek life, such as the Stadion, for foot racing, and the Hippodrome, for horse racing.

Of the domestic works of the Greeks little is known, for comparatively little attention was paid to personal accommodation. However, the houses of Pompeii, which will be described later, contain so many characteristics of Greek work, that it is reasonable to assume that the houses of the Greeks were very similarly arranged.

Constructional Methods

One of the finest qualities of Greek architecture was its truthfulness. The Greek builders accepted the limitations of the materials available, and set out to use them faithfully, making each feature do that which it appeared to be doing : rarely was there any deception.

Materials. The materials used by the Greeks were marble, stone, timber, bricks, and terracotta. Of these, the timber has decayed, and the bricks, which were sun-dried, have not stood the test of time ; terra-cotta ornaments have been found, and are to be seen in many museums.

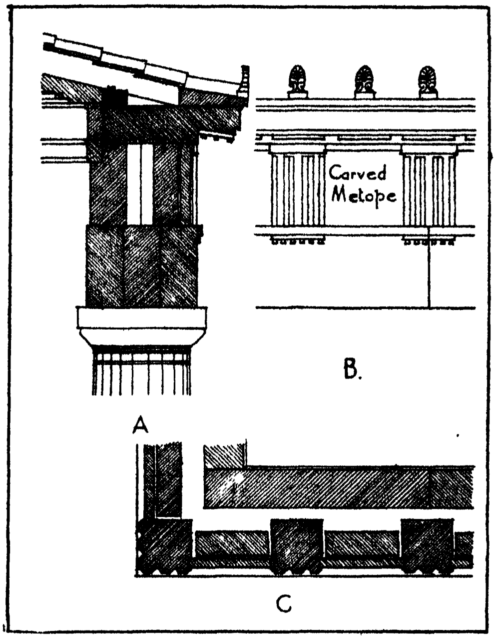


FIG. 19. THE CONSTRUCTION OF THE GREEK DORIC ENTABLATURE
A = Section through Entablature. B = Elevation
C = Plan through frieze

Most of the temples in Greece were built of marble, the best known being Pentilic from Mount Pentilicus, near Athens. A grey marble was frequently used for paving and the stylobate, also as a foil to the sculpture in friezes.

In the colonies, a type of limestone was generally used. Here, in order to produce a fine surface consistent with the delicate mouldings in which the Greek delighted, important surfaces were usually covered with a thin layer of marble dust stucco. The resultant finish was hardly distinguishable from marble.

WALLS. These were usually built of big blocks of stone without mortar. The bottom course was usually higher than the remainder (Fig. 20, A). Joints were finely worked, but there does not appear to have been any real bond ; metal cramps were sometimes used in thick walls. It appears from remains that surfaces were not finished until the walls were built, when the last ⅜ in. or so was dressed off, but many buildings never had this final finish (Fig. 20, B).

COLUMNS were sometimes monolithic (of one stone), but usually consisted of a number of drums, or sections. These were first roughly shaped, with *ancones*, or projections, left on for hoisting. The inner part of the bed was sunk, and the drums were revolved on one another or on sand so as to produce a fine joint (Fig. 20, C). Flutes were worked afterwards when the column was built.

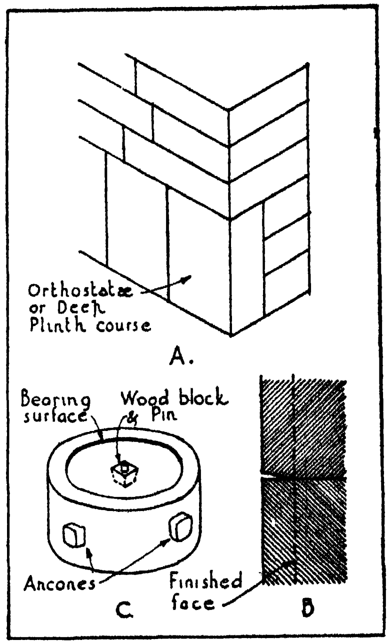


FIG. 20. MASONRY DETAILS

LINTEL. This was usually a single stone, but in larger temples two or three stones were used side by side. It will be appreciated that the spacing of columns was determined largely by the spans over which stone lintels could be used with safety.

FRIEZE. This was the middle member of the entablature. In the Doric Order, the triglyphs carried the cornice, and the carved

metopes were loosely fitted so as to avoid cracking in case of settlement.

CORNICE. This was sometimes of a harder stone, and was built up as shown in Fig. 19.

ROOFS. These were probably constructed of timber, of which no traces remain. The roof covering consisted of terra-cotta and marble tiles (Fig 21). These were stopped at the eaves by *antefixae* (Figs. 22 and 27), which were carved or painted. In some cases, a gutter was formed, as in Fig. 21, C, with carved gargoyles, through which the rain-water ran off.

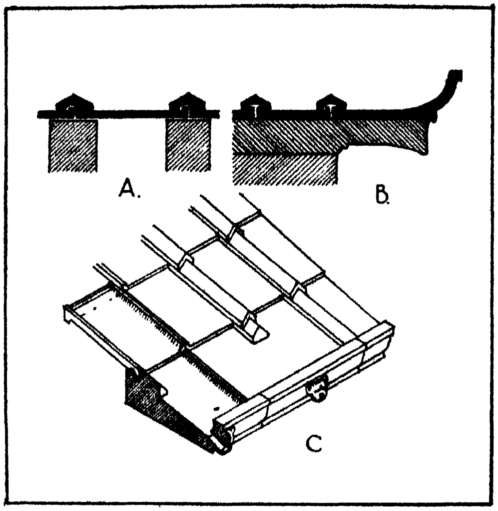


FIG. 21. DETAILS OF ROOF TILING

= From Bassae. B = The Parthenon. C = Diagram showing arrangement of gutter.

Ceilings over the outer passages, or ambulatories, were of stone or marble, and were deeply coffered, while those inside the building were of similar design, but constructed of timber, and painted.

ORDERS

Those architectural forms which were evolved out of the use of the simple column and lintel are known as the *Orders*; they were developed to a state approaching perfection by the Greeks.

Doric. The oldest of these Orders was the Doric Order, which many authorities have attemped to trace back to an Egyptian prototype, while others ascribe its form to the influence of timber origin. These theories are interesting, but it appears probable that the Doric Order was the result of the normal development of building in stone, with the refinements of which it is known that the Greeks were capable.

The Doric Order is essentially the typical Greek Order (Fig. 22). The column, which is from four to six-and-a-half diameters high, has

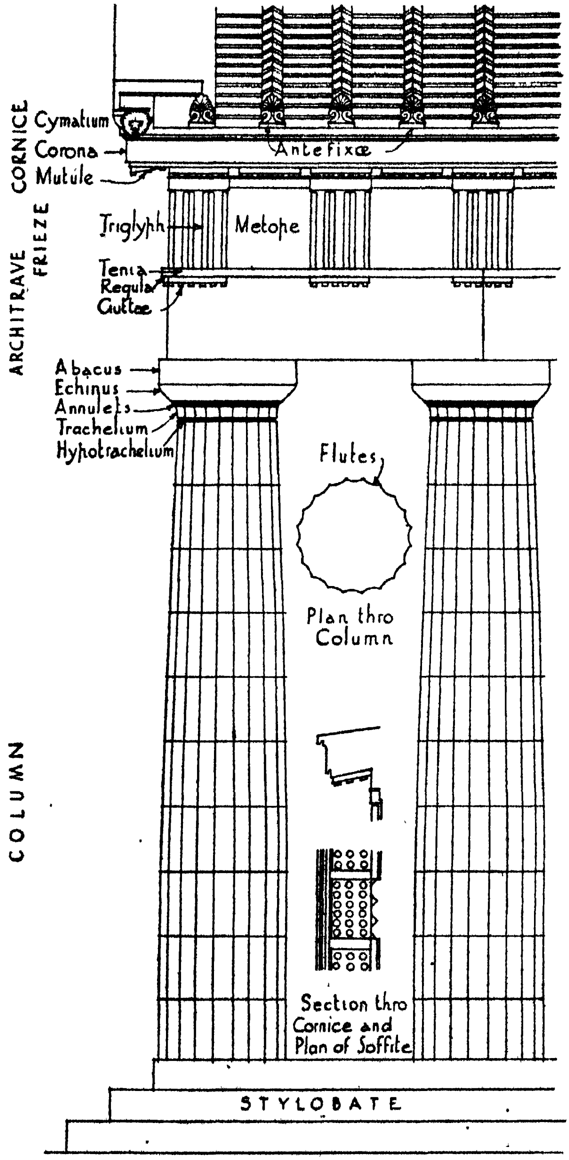


FIG. 22. THE GREEK DORIC ORDER

no base, but stands upon a platform, usually of three steps, called a *stylobate*. There are a number of channels in the length of the column, known as *flutes*, ranging from twelve to twenty-four in number, twenty occurring in the best examples. The column is tapered, diminishing to about two-thirds or three-fourths of its

diameter at the top. The sides are usually curved in a convex manner, known as the *entasis*. This was presumably adopted as a correction of an optical illusion which makes straight sides appear to curve inwards. At the top of the column is a *capital*, consisting of an *echinus* and an *abacus*. The former is circular on plan, boldly curved in profile in early examples, tending to be straighter in later work. The abacus is a square slab upon which the

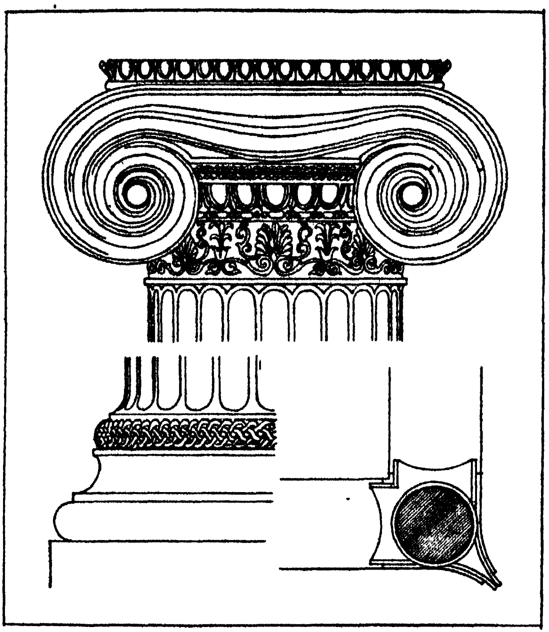


FIG. 23. CAPITAL AND BASE
From the North Porch of the Erechtheion at Athens. The diagram shows the method of treating the angle capital

lintels rest. At the lower part of the capital are a number of fillets, known as *annulets*; below, on the lower edge of the block of stone forming the capital, is a splayed groove called the *hypotrachelium*, and the band between, the *trachelium*.

ENTABLATURE. This is about one-third the height of the column, and consists of three parts —*architrave*, *frieze*, and *cornice*. The architrave is the lintel proper, and has one vertical face with a flat moulding at the top called the *tenia*; a small member known as the *regula*, with six small *guttae*, occurs at intervals under each triglyph.

The frieze contains *triglyphs* and *motopes*, regularly spaced, the former occurring over the columns and the centres of the bays; at the corners of the building the frieze ends with a triglyph, the end columns being consequently more closely spaced than the remainder. The metopes usually contain sculpture.

The cornice, or crowning part, consists of a projecting stone, forming an eaves, on the underside of which are flat projections known as *mutules*, usually decorated with rows of guttae.

Ionic. This order is chiefly distinguishable by its scroll or volute capital (Figs. 23 and 24), which seems to have some connection

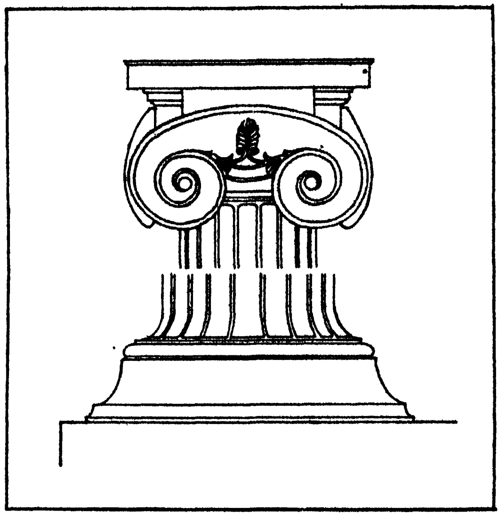


FIG. 24. CAPITAL AND BASE
From the Temple of Apollo Epicurius at Phigaleia

with the spiral forms which were used by the Egyptians and Assyrians.

Columns are usually about nine diameters high, including the capital and base, and as a rule have twenty-four flutes. These are separated by fillets, and not by arrises as in the Doric Order. Bases are moulded, and consist usually of an upper and lower torus separated by a scotia and fillets; examples are shown in Figs. 23 and 24. Capitals consist chiefly of a pair of spirals or volutes, with a shallow abacus. They were, in many cases, beautifully enriched with carving.

ENTABLATURE. This consists of three members, as does that of the Doric Order; it varies in height, but is usually about one-fourth of the height of the column. The architrave is usually subdivided into three parts, with an enriched moulding at the top. The frieze is usually plain, but in some cases is decorated by a continuous band of sculpture.

The cornice has no mutules, but rests upon

a bed mould, which frequently includes a series of square projections known as *dentils* (Fig. 25).

Corinthian. This order was not developed to the same extent as those previously referred to. The chief characteristic is the capital, which is an elaboration of the Ionic order,

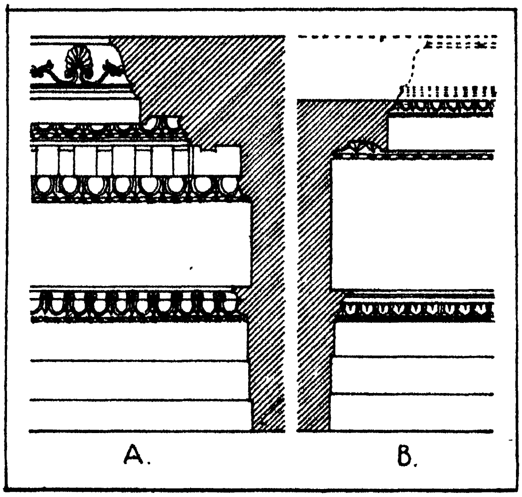


FIG. 25. GREEK IONIC ENTABLATURES
A = Temple of Minerva Polias, Priene. *B* = The Erechtheion, Athens

but deeper, see Fig. 26. An interesting variation from the Temple of Winds is illustrated in Fig. 10.

THE PEDIMENT

An important feature which was evolved by the Greeks is the pediment. This is the name given to the gable at the end of the building, which is formed by carrying up the cornice to conform to the slope of the roof. An additional member—the *cymatium*—is included in the pediment, and returned round the angle and stopped, as in Fig. 21. In some cases, this member was formed by the end tile (Fig. 21, B).

The triangular space enclosed (the *tympanum*) was the focal point in the design, and frequently contained sculpture, those on the Parthenon being particularly interesting examples.

The anta (plural, *antae*) is a form of pilaster, used at angles, and against walls, to support the end of an entablature. The proportions, bases, and capitals are usually different from those of the orders; an anta capital from the Erechtheion is shown in Fig. 27.

MOULDINGS AND ORNAMENT

Greek mouldings were refined and delicate, possible in a country with a sunny climate, where every subtle curve had its effects of light and shade, and capable of execution in the fine-grained marble which was generally used. The profiles of the mouldings were usually free curves approximating to conic sections, such as ellipses. Typical mouldings and their enrichments are given in Fig. 27.

This was very refined in character, and was based chiefly on the acanthus leaf and the scroll. The former was derived from a plant which grows wild in Southern Europe; there are two varieties, one with a very pointed leaf, and the other much broader. The former is the one used in Greek work, while the latter found favour with the Romans. A very much used ornament was the *anthemion*, which was employed on the

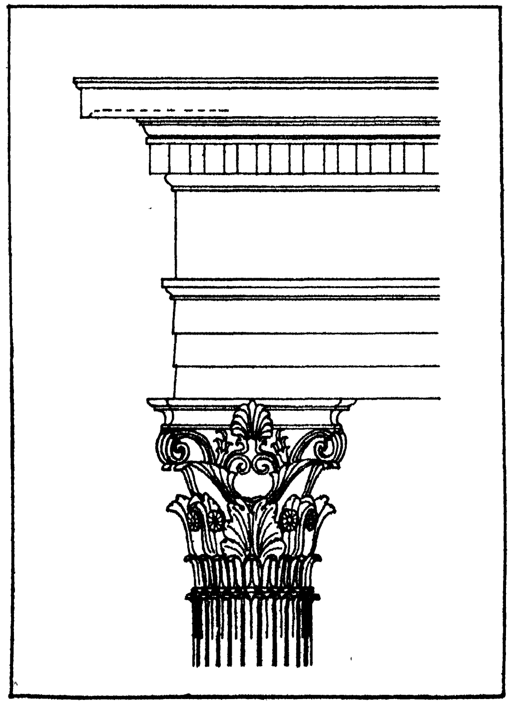


FIG. 26. THE GREEK CORINTHIAN ORDER
From the Choragic Monument of Lysicrates, Athens

antae at the Erechtheion. Among other enrichments used were the *guilloche*, which decorates the base in Fig. 23, the *bead and reel*, and those shown in Fig. 27.

Colour. From the few traces which remain, it seems certain that the Greeks decorated many of their buildings with colour. Mouldings and enrichments were painted, and coloured backgrounds provided for sculpture; sometimes whole buildings were painted, the colours used

being strong hues of green, blue, red, and yellow.

The Greeks not only exercised great care in the execution and detail of their work, but showed great ingenuity in adjusting proportions so as to correct optical illusions. *Entasis*, to which reference has been made; the raising of the entablature and stylobate towards the centre to prevent the appearance of sagging; the close spacing of end columns, producing an added appearance of stability, and the inclining of columns inwards in a pyramidal form for the same reason; the slight thickening of angle columns because they would appear slender when silhouetted against the sky. These were typical refinements which, in the hands of such skilled designers, produced an architecture which was the perfect expression of a nation's ideals.

For sincerity and culture it has never been surpassed, but admiration must be tempered with a discreet appreciation of the conditions which produced it, and the realization that although the great works of the Greeks may inspire all who see or study them, they are not models suitable for reproduction as solutions of the architectural problems of modern civilization.

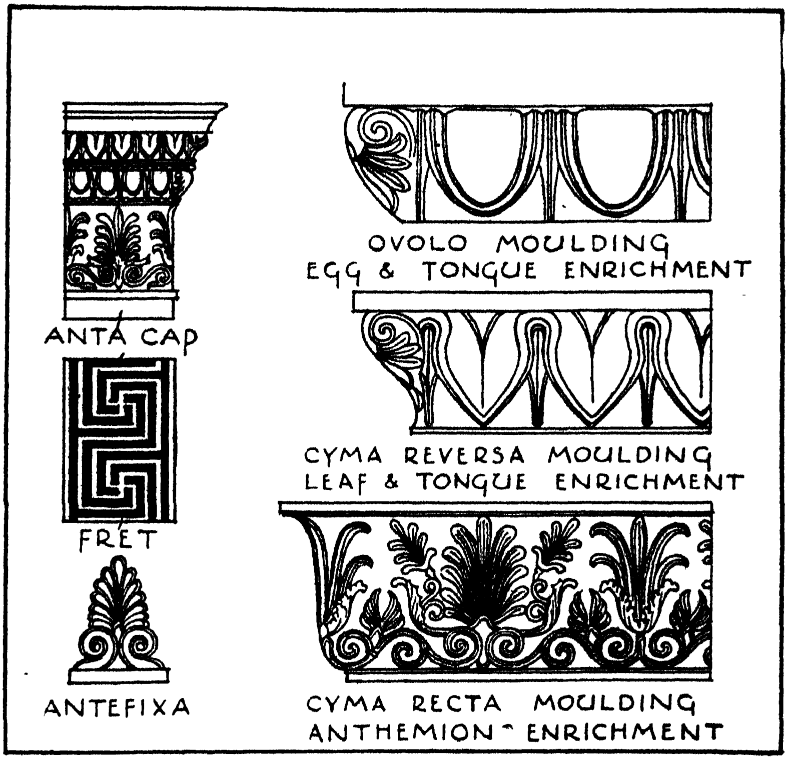


FIG. 27. GREEK MOULDINGS AND ENRICHMENTS

Sculpture. Greek sculpture was undoubtedly the finest ever produced. Perhaps the best was that by Phideas at the Parthenon. The extreme thoroughness of the work is illustrated in the groups in the pediments of this building, where the figures, though seen only from the front, are almost detached, and are perfectly modelled all round. Words cannot adequately describe the beauties of this work; it represents Greek art at its best, and has never since been equalled. There are many fragments and restorations in the British Museum which should be studied by all who desire to understand the wonderful perfection of Greek art.

Chapter III—ROMAN ARCHITECTURE

The People and Their Buildings. The early history of the great Roman Empire is so wrapped up in legend, that it is difficult to distinguish between fiction and truth. It is generally accepted, however, that Rome was founded in 753 B.C. by a number of people, who established themselves on the Palatine Hill. There they built a walled city, and soon obtained supremacy over the surrounding tribes. The best known were the Etruscans, a people whose origin is obscure. Their works appear to have consisted chiefly of walls and tombs, although Vitruvius, a Roman writer of the first century A.D., whose

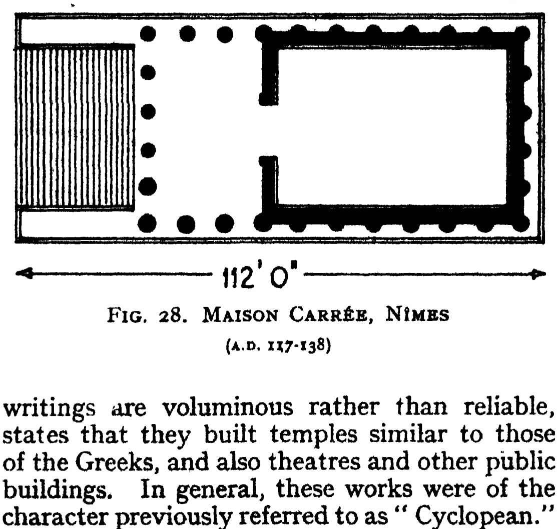


FIG. 28. MAISON CARRÉE, NÎMES

(A.D. 117-138)

writings are voluminous rather than reliable, states that they built temples similar to those of the Greeks, and also theatres and other public buildings. In general, these works were of the character previously referred to as "Cyclopean." There was, however, one feature which must be accepted as the seed of the great styles of architecture which were to spread over the whole of Europe: *that feature was the arch.* Although there is no definite information about the origin of the arch, it is probable that it was used in Asia Minor, as well as by the Etruscans, but its possibilities do not appear to have been fully appreciated.

There are no remains to suggest the existence of important buildings in the early days of Rome, but this is not surprising when it is remembered that the Romans were a stern, realistic nation, whose great object was to rule over all the nations with whom they came in contact in their efforts to discover the world. The history of the Roman Empire—too well known and too lengthy to discuss here—is a story of unremitting energy, of wonderful organization and discipline, and of united effort in the search for prosperity and power. No efforts were spared, and apparently no obstacle unsurmountable in the endeavour to develop the countries which came under Roman rule. In all the countries which once formed this great Empire, evidence is found of the roads, bridges, waterways, and other engineering works of stupendous nature, characteristic of the practical outlook of the great people.

How natural, then, that they should have no time for the arts of peace! The desire to create, rather than to perfect, is the temperamental quality of the Roman Empire which is reflected in its architecture, and in which it differs so from that of the Greeks.

It was after Greece became a Roman province, in 146 B.C., that the desire to create beautiful buildings showed itself. Artistic treasures were pillaged and taken to Rome, and Greek architects and workmen were introduced to the capital. There the great constructional skill of the Romans and the artistic ability of the Greeks were associated in the production of buildings which were to equal in grandeur the Empire itself. The influence of Roman work naturally spread throughout the length and breadth of the dominion, and was the foundation of European architecture. There was little change in architectural character during the four or five hundred years when the Empire was flourishing, although there was an effort on the part of many of the emperors to outdo their predecessors in the magnificence and style of their buildings. The capital was removed to Byzantium (Constantinople) in A.D. 324, and soon afterwards the Empire was divided into two parts, East and West. Although the Western Empire did not come to an end until A.D. 475, the history of Roman architecture is considered to terminate about A.D. 330, for in the year A.D. 313, Constantine legalized Christianity, and the works which followed are usually known as Early Christian.

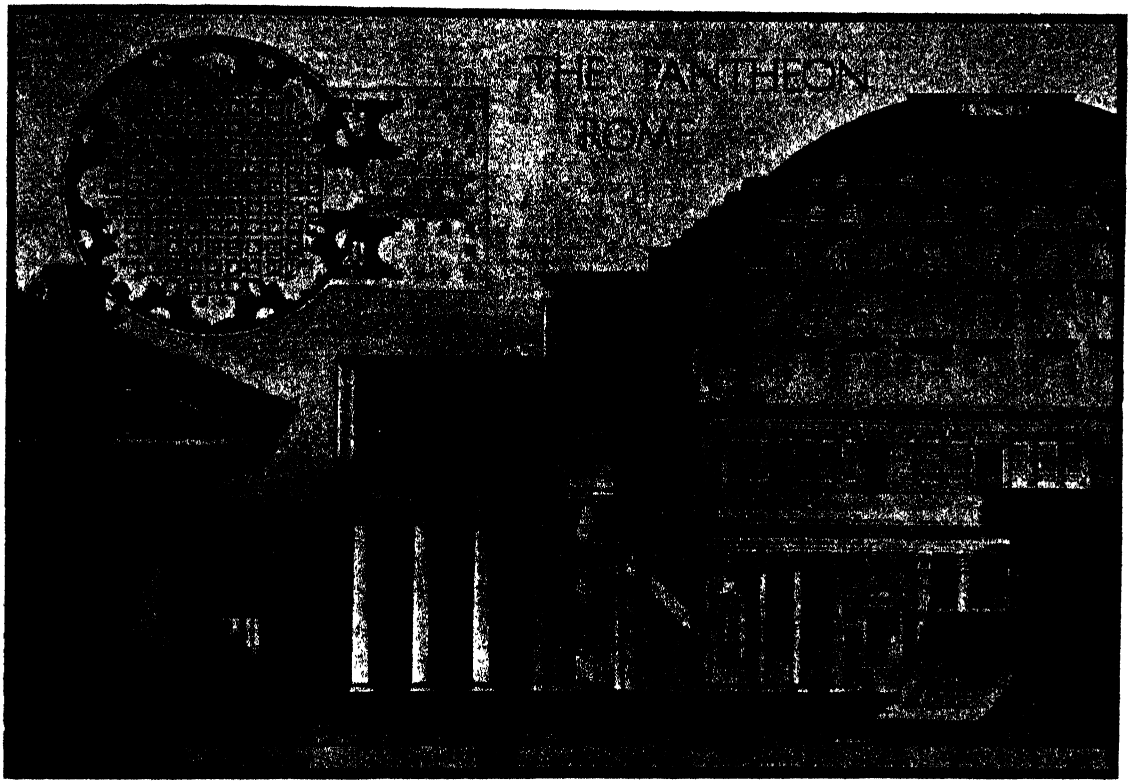
The Eastern Empire, after many vicissitudes, passed into the hands of the Turks in A.D. 1453.

The architecture of Byzantium will be dealt with later.

When considering the buildings which were such an important part of this great civilization, it is well to bear in mind a factor which greatly influenced the character of architecture —the use of concrete.

Before the beginning of the Christian era, the Romans had mastered the use of concrete. With the almost unlimited and cheap slave labour, which their power and wealth enabled them to employ, they could build cheaply and speedily. Although the Romans were not, perhaps, artistic, they were an imaginative people, and their ingenuity in the use of concrete enabled them to solve the many great building problems which the desire for magnificence created.

Temples. The story of Greece is almost entirely told by the temples; this is not the case with the Roman Empire, although there existed a pagan religion with similar gods but with different names. Roman temples were part of the constitution, and appear to have served at times for certain official purposes. Part of the temple of Castor and Pollux, for example, was used as an office of weights and measures. The Romans were not consistently a devout people, and although many temples were built, few now remain. Many appear to have been pulled down to make way for bigger and grander building schemes, and others were doubtless demolished to provide space and material for the early Christian churches. The temples were based upon the Greek model, with a few important variations; the plan usually consisted of one cella, or chamber, with a deeply recessed portico at one end. In many cases, the cella was covered by a barrel vault of stone or concrete.



Student's Drawing: Northern Polytechnic School of Architecture.

FIG. 29. THE PANTHEON, ROME

Externally, they closely resembled the usual Greek form, but were placed upon a podium wall, which projected to enclose a flight of steps.

The best preserved temple existing is the building now known as the Maison Carrée at Nîmes in France (Fig. 28). It is interesting to

note that though columns were employed in the traditional manner to form a portico, their use on the sides and back of the temples was purely decorative or imitative. The magnitude of

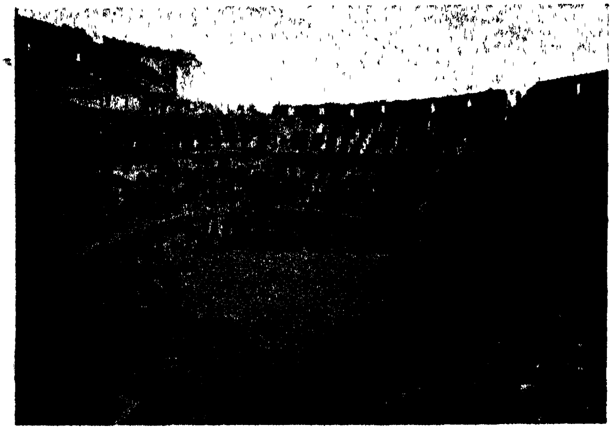


FIG. 30. THE INTERIOR OF THE COLOSSEUM, ROME, AS IT STANDS TO-DAY

some of the Roman work is illustrated in the great Temple at Baalbek in Syria. There the columns, of which six remain, were about 65 ft. high, supporting an entablature 13 ft. high. The substructure of the temple was built of gigantic stones, the three largest being each about 64 ft. long, and weighing about 500 tons.

Some circular temples existed, the best known being the Pantheon, one of the greatest of Roman works. The circular portion, known as the Rotunda, was erected by the Emperor Hadrian about A.D. 120–124. It is covered by a vast hemispherical dome 142 ft. in diameter, constructed of brickwork and concrete. Fig. 29 shows the plan, interior treatment, and some details.

Theatres and Amphitheatres. The Romans built a number of theatres which were based on those of the Greeks. In the central space, instead of a chorus, seats were provided for the more important State officials, while the stage was raised and increased in importance. They were not usually hollowed out of the hillside, but were built up on a system of concrete and stone vaults over corridors used as exits and retiring spaces (see Fig. 30).

The amphitheatres were the more characteristic Roman places of amusement, and were devoted to gladiatorial combats and similar displays, more suited to the Romans who preferred this sterner form of "amusement" to the drama of the stage. They were usually oval-shaped on plan, with tiers of seats all round an open arena. The best known example—the Colosseum, Rome (A.D. 70–82)—was about 620 ft. long by about 513 ft. wide, surrounded by a wall of 157 ft. high, the architectural treatment of which will be referred to later. There were other similar places of amusement, such as circuses, which were used for horse and chariot races. Their magnitude will be appreciated when it is stated that one, the Circus Maximus at Rome, is believed to have accommodated about a quarter of a million spectators.

Basilicas. These served both as meeting-places for business men and as halls of justice. They were usually rectangular in plan, with rows of columns running all round internally, forming aisles, and one or more semicircular recesses or apses for the judges.

One of the finest was Trajan's Basilica at Rome (A.D. 98), a vast building about 385 ft.

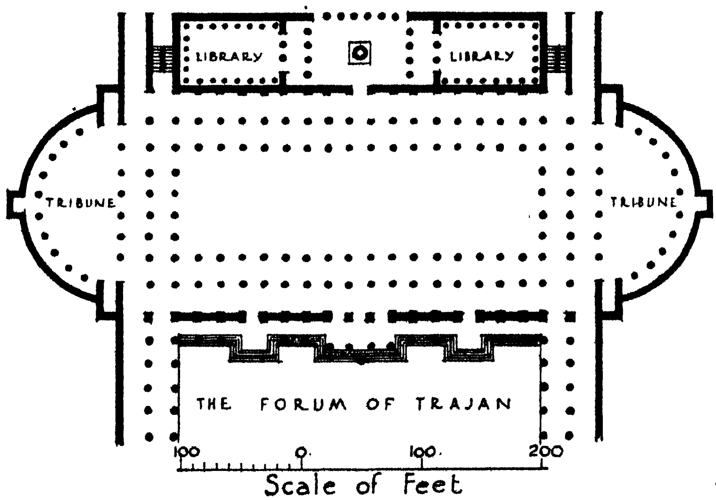


FIG. 31. TRAJAN'S BASILICA, ROME

long and 182 ft. wide (Fig. 31). Two rows of columns were ranged all round, leaving a central nave 87 ft. wide, which was covered by a timber-framed roof, with a coffered ceiling. The total height internally was about 120 ft.

The Basilica of Constantine (A.D. 312) was an interesting example, having a rectangular nave

Student's Drawing, Northern Polytechnic School of Architecture

FIG 35 A COMPOSITION OF ROMAN DETAILS

about 265 ft. long, 83 ft. wide, and 120 ft. high, with three bays on each side (Fig. 32). It was

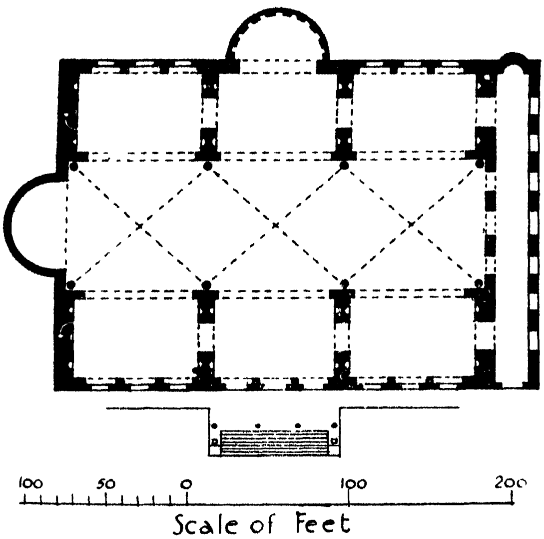


FIG. 32. THE BASILICA OF CONSTANTINE OR MAXENTIUS, ROME

covered by a vast groined vault. The arrangement of the plan is interesting, as it shows the special arrangement of piers to support the thrust and load of the vaults, which are concentrated at a few isolated points instead of being

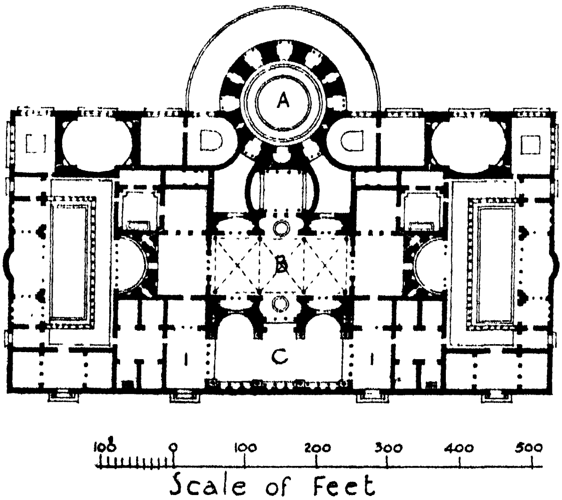


FIG. 33. BATHS OF CARACALLA, ROME
A = Calidarium. B = Tepidarium. C = Frigidarium

distributed evenly along a wall. This system is in many respects similar to that employed later in Gothic cathedrals.

The remains of basilicas found in many of the one-time outposts of the Roman Empire suggest a magnificence characteristic of the importance attached to commerce and the administration of justice.

Thermae. Although generally known as the "baths," these buildings were probably inspired by the Gymnasia of the Greeks, already referred to. They are all in a very ruined state; but from the few remains and from ancient writers, it is evident that they were magnificent buildings, not only used for bathing on a most luxurious scale, but as rendezvous for the people's pleasures and exercises. They entered very largely into the life of a pleasure-loving people,

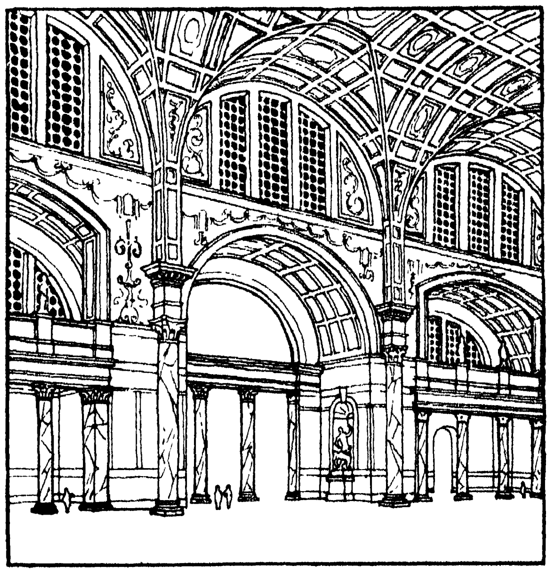


FIG. 34. A ROMAN INTERIOR

and were characteristic of the grandeur and magnificence of Rome in its prime. They consisted principally of a great central building, of which the Baths of Caracalla, Rome (A.D. 212–235), are typical (Fig. 33). The three principal apartments were the *calidarium*, or hot room; the *tepidarium*, or warm lounge; and the *frigidarium*, or cooling room, containing a huge swimming pool. These, with sundry other apartments for massage, etc., completed the arrangements devoted to bathing on a grand scale.

This central block was usually raised from the ground, the lower floor or basement containing the furnaces and other services connected with the building.

In this building some 1,600 bathers could be

accommodated, while in a somewhat later establishment, erected by Diocletian (A.D. 302), over 3,000 persons were provided for.

The main building was surrounded by ornamental gardens, with a stadium for athletic sports, and by buildings which included small theatres and lecture rooms for orators, and accommodation for the slaves constituting the staff of the establishment.

Internally, these great buildings were lavishly decorated with marble and mural paintings, while the many art treasures, pillaged from Greece and other places, were set up there (Fig. 34). Externally, they appear to have been very simply treated with stucco, or the brick walls left plain.

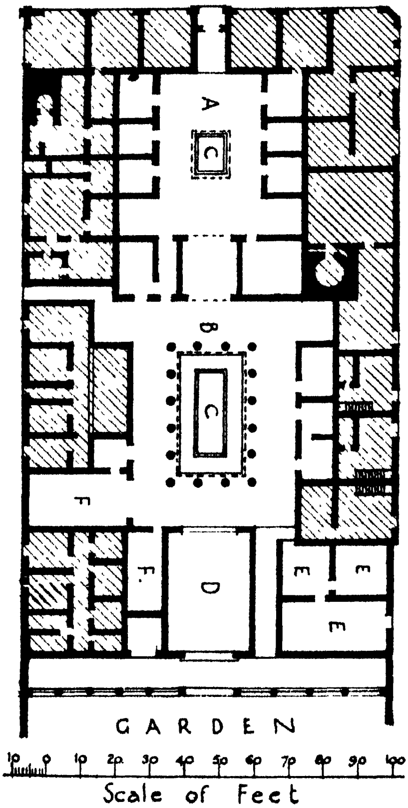


FIG. 36. THE HOUSE OF PANSA, POMPEII

A = *Atrium* *B* = *Peristyle.* *C* = *Impluvium*, or water cistern. *D* = *Oecus*, or Reception-room. *E* = Kitchen, etc. *F* = *Triclinium*, or Dining-room. The hatched portions of the plan indicate shops, etc.

Tombs. The tombs of the Romans were frequently impressive structures. A type of special interest was the Cenotaph, or monument, to the memory of a person buried elsewhere.

The Triumphal Arches and Columns, erected by the emperors to commemorate victories, are of great interest. One of the best known is the Arch of Constantine (Fig. 5).

Many of the buildings which have been described were grouped around an open space, known as the *forum*. This was a central public square or "place" used as a market or place of assembly.

Houses. Domestic buildings were of three kinds: the *villa*, or country house; the *domus*, or private house in the town; and the *insula*, or tenement building. The first frequently attained vast dimensions, including as it did many of the amenities of town life, such as thermae, theatres, and gymnasia.

The domus, of which the House of Pansa, Pompeii (Fig. 36), is a good example, consisted of two main parts. The outer, grouped around an *atrium*, or open court, contained reception and business rooms, while the more private apartments were arranged around an inner colonnaded court or *peristyle*.

CONSTRUCTIONAL METHODS

The Romans, as a nation, were a thoroughly practical people, with unrivalled skill and inventive powers in construction.

Their early buildings indicate that they accepted the traditional methods of the Greeks and Etruscans, particularly in their temples, which were for the most part based on the Greek form.

Concrete. Later, however, these traditional methods were found to be too costly and too slow for the vast building schemes which the flourishing nation required, and the use of concrete became general. Although this material had been used for some time, it was from the first century B.C. onwards that it was used so extensively.

The concrete of the Romans owed its great strength to the qualities of certain volcanic deposits known as *pozzuolana*, found in great quantities near Rome; this was mixed with lime, and when set was exceedingly hard. Concrete was used for foundations in a manner very similar to that employed at the present day. It was cast between rows of planking, which were removed when the concrete was set. For the superstructures, walls were usually faced with stone or brick; two interesting methods are illustrated in Fig. 37. Arches were treated in a similar manner to the walls in which they were formed, with bonding courses at intervals extending right through the walls.

Vaults. Roman vaults were generally constructed of concrete, a material eminently suited for this purpose on account of its homogeneity when set. For this reason, concrete vaults exerted little thrust, a factor which simplified

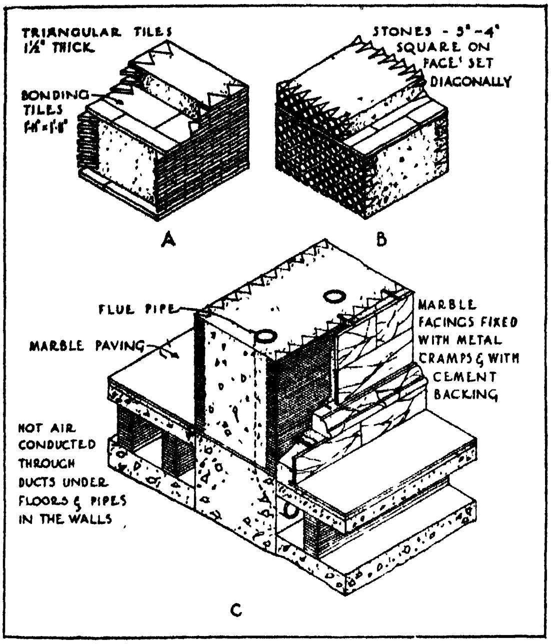


FIG. 37. CONSTRUCTIONAL DETAILS

A = Concrete wall faced with bricks
B = Concrete wall faced with stones
C = Diagram illustrating system of heating and marble facing

their use over large spans. Their construction was very largely determined by the need for economy in centering, or timber supports, during erection. Brick ribs, or arches, were formed at intervals, these being supported until completed, and the spaces, or bays, between were filled with a thin layer of concrete. When this was set, it was strong enough to support the remainder of the concrete. In some cases, layers of tiles were first placed on light centering, forming a flat type of arch. These two together formed a bed sufficiently strong to support the first layer of concrete, which was added to when set. Fig. 38 illustrates these methods.

Fig. 39 gives an excellent idea of the massive character of the Roman vaults.

They were of three general kinds: ***barrel***, ***cross*** (or ***intersecting***), and ***domical***.

The first, the barrel vault, which was used generally to cover small spaces, required continuous walls for its support, whereas the cross, or intersecting, vault was used in the larger buildings, and was formed by the intersection of two vaults, usually of equal span. The lines formed at the intersections are known as ***groins***. This vault, it will be seen, only required support at the four corners; when used over long halls, bays were formed by piers, as in Figs. 32 and 34, each bay being covered by a cross vault. This arrangement permitted the placing of windows in the upper part of the walls; see Fig. 34.

Domical vaults, or domes, were used over circular buildings, such as the Pantheon, and in the form of semi-domes over recesses, such as those in the Basilicas.

Although it is safe to say that without concrete the great buildings of the Romans would never have existed, it must not be supposed that

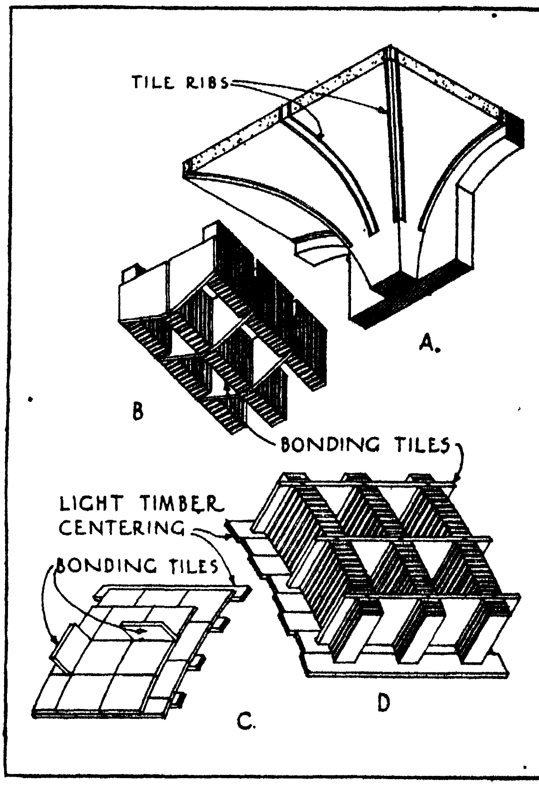


FIG. 38. VAULT DETAILS

A = Section of vault showing position of ribs
B = Detail of rib
C and *D* = Arrangements of tiles in barrel vaults

no other materials were used. It will have been observed that brick and stone were employed as a facing for concrete walls, but they were also used in the traditional manner.

While there are no remains in Rome of

walls built entirely of bricks, some have been found in the provinces. This is largely accounted for by the fact that many bricks are sun-dried; those which were burnt in kilns are found in a very good state of preservation, with the maker's name impressed.

Masonry. The building stones of the Romans were Tufa, Peperino, and Travertine, the first

FIG. 39. THE REMAINS OF THE BASILICA OF CONSTANTINE, ROME

two being of volcanic origin. Tufa was used in the early buildings; it had poor weathering qualities, and was usually stuccoed. Peperino, a harder stone, was next in general use, while later, Travertine, a hard limestone, was employed, particularly in positions where great strength was required. The Romans accepted the Greek practice of using large blocks of stone, a length of 15 ft. being quite common. Masonry was sometimes built in mortar, and at others, where a sufficiently fine joint could be worked, metal cramps only were used. Stones frequently had a chiselled margin on the face, a decorative finish which was possibly evolved out of the methods of stone dressing used by the Greeks. In some later work, vaults were built of stone; the custom in many cases was to build the arched ribs first, using one centre and moving it along as each rib was completed, and then to fill in between these ribs with thin slabs.

It was the boast of Augustus that he found Rome brick and left it marble. But although, during the great Augustan age, many temples were constructed of solid marble, the general practice was to face the concrete walls and piers with a veneer of this material. In the early days of the Empire, Grecian marbles were used, but later, Italian quarries were opened and Carrara, Pavonazzo, Cipollino, and other varieties were used. Marble facings were at first extremely thick—about 6 in.—but later, they were reduced to about 1 in. They were secured by metal cramps with a backing of cement (see Fig. 37). Columns were usually monolithic (of one stone), and it is interesting to note that the Romans showed an appreciation of the decorative qualities of coloured marble, by omitting the fluting, thereby showing the full beauty of the colour. Granite, alabaster, porphyries, and many of the rarer materials of decorative value were imported and used to add to the richness and splendour of their buildings.

Stucco. Although this material was so frequently employed as a facing to walls of concrete or rough stone, it was applied with considerable care and skill. Marble dust was an important ingredient, the presence of which made it possible to polish the surface. Stucco also provided an excellent surface for decoration in colour.

Bronze was used to a large extent, both constructionally and for decorative purposes. The coffered ceilings and roof tiles of the Pantheon, Rome, were of bronze, in some places plated with gold.

Timber. There are practically no remains of Roman carpentry, but it is almost certain that the roofs over early temples and some of the later Basilicas were of timber. Apart from the scarcity of timber, its inflammability appears to have been a reason for its neglect as a building material.

Important buildings, such as the Baths, were heated by means of hot air, which was circulated from furnaces in a basement through flues in the walls and floors (see Fig. 37).

Roman constructional methods were essentially different from those of the Greeks; although it is, perhaps, too severe to say, with many writers, that the Romans employed deceptive methods, it is very evident that by their inventive genius, they made construction subservient to their requirements; they did not hesitate to adopt any methods to solve the problems which the production of their great buildings of unparalleled magnificence required.

ORDERS

The Romans adopted the "Orders" from the Greeks, but used them in a decorative, as well as a constructional manner. It has been pointed out that columns were frequently attached to

walls, so that they were not structurally essential as supporting members, although they sometimes served as buttresses. For this reason it will be appreciated that the spacing of the columns was not of necessity determined by the safe span of a lintel, but could be modified to suit the circumstances.

The three Greek Orders were used, with many variations, and two others added, which complete the "Five" Roman Orders, to which reference is usually made. The new ones were the *Tuscan*, a form of Doric borrowed from the Etruscans, and the *Composite*, in which the capital was a combination of those of the Ionic and Corinthian Orders. The chief characteristics of the Roman Orders were as follows.

Tuscan. This was a plain sturdy form of the Doric Order, with a simple capital and base to an unfluted column, and a rather plain entablature without triglyphs or other enrichments. It was rarely used by the Romans, but possesses great dignity, as may be seen in the famous colonnade which leads to the Church of St. Peter, Rome.

Doric. The Roman version of this Order was less massive, but lacked the refinement and delicacy of the Greek Order from which it was derived. The column was about eight diameters high, and was used both with and without flutes. A base was added, and the capital was varied considerably (see Fig. 40). The triglyphs in the frieze were retained, but the spacing was varied, a triglyph being placed over the axis of the column at angles. A dentil course was, in some cases, introduced into the bed-mould of the cornice.

Ionic. There was little difference between the Greek and Roman examples of this Order, although the columns of the latter were more slender (Fig. 41). The volutes on the capitals of the Roman were smaller, and in later examples were sometimes angular.

Corinthian. This was the most popular Order of the Romans, and was used in most of their temples and important buildings. The capital consisted of an abacus, angle-volutes, and rows of leaves growing out of a necking (Fig. 42).

Capitals were of great variety, and in later work were over-elaborated, rams' heads and similar motifs taking the place of the volutes. Bases were similarly varied, but not usually enriched with carving. The shaft of the column, usually from 9½ to 10½ diameters in height, was fluted when stone was the material used, but generally plain when built of marble or granite.

It was in the entablature, and particularly the cornice, that the Romans excelled. Although, in the first and second centuries A.D. the entablature was fairly simple, it was later

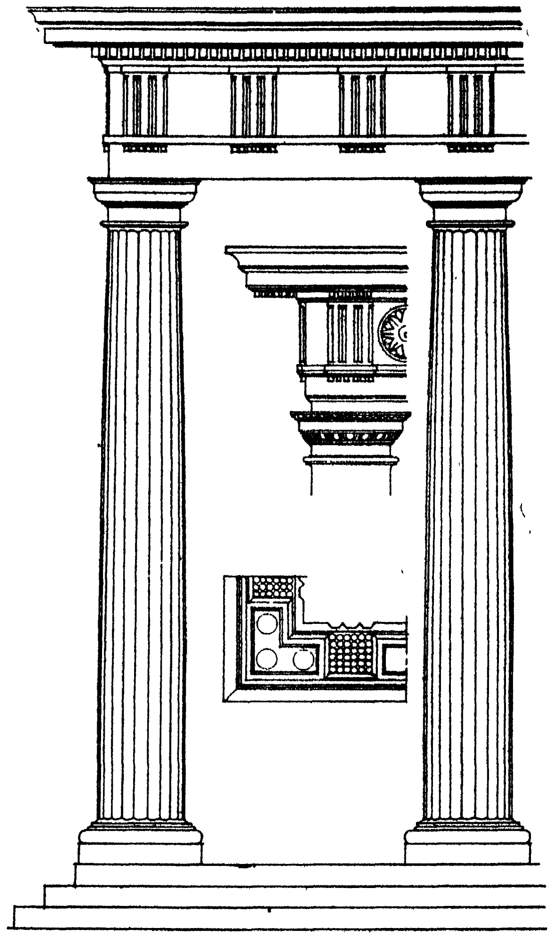


FIG. 40. THE ROMAN DORIC ORDER
The complete Order shows the "Denticulated" entablature
Inset) Details of the "Mutular" entablature

greatly enriched, sometimes, perhaps, to excess. Brackets, known as *modillions*, were introduced immediately below the upper members of the cornice, and the various mouldings were enriched with carving. The frieze sometimes contained ornament in relief.

Composite. This Order, which was employed in many of the triumphal arches, differs chiefly from the Corinthian in the details of the capital, in which the volutes are increased in size; this variation does not appear to be an improvement. Modillions, if employed, are usually simple

blocks, and the columns are more slender than those of the prévious Order.

Application of the Orders. Although the Romans used the Orders in the traditional manner, it was their employment in combination with arches, for the decoration of wall surfaces, that produced such grand effects in the larger buildings. Another factor which influenced their arrangement was the need of the Romans for buildings of more than one story. The invariable practice was to employ a separate Order for each story, and it is of importance to note that a definite sequence was usually preserved, the sturdiest Order being used at the bottom, and the more slender at the top of the building.

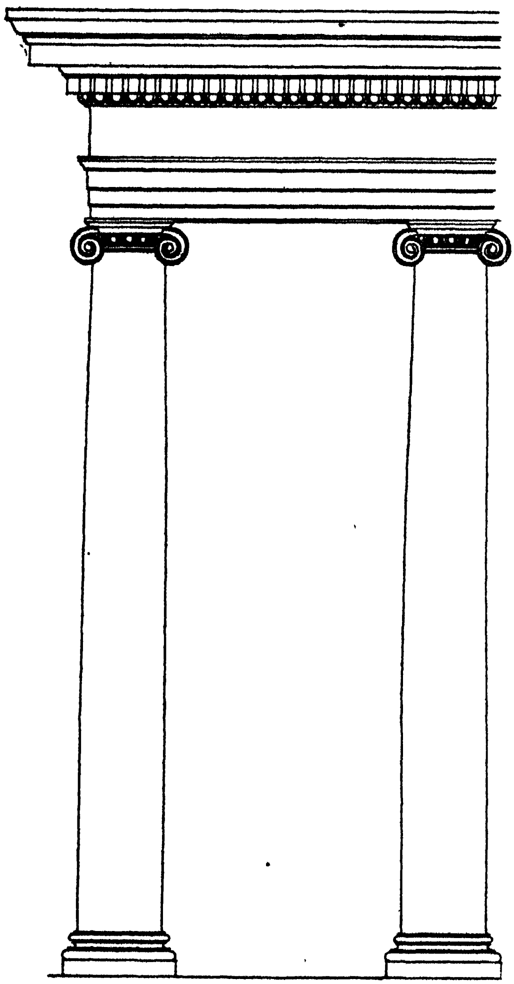


FIG. 41. THE ROMAN IONIC ORDER

Fig. 43 shows an arrangement of superimposed Orders in the Colosseum.

Columns were frequently placed on pedestals.

DETAILS AND ORNAMENT

OPENINGS. Window and door openings were either square or semicircular headed, the larger window openings, such as the windows in the Baths (Fig. 33), being subdivided by mullions. The door of the Pantheon, a very fine example, is illustrated in Fig. 29.

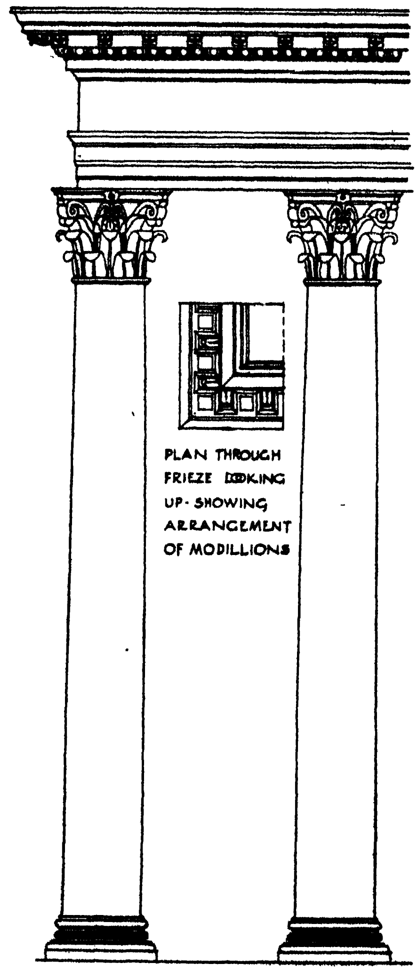


FIG. 42. THE ROMAN CORINTHIAN ORDER

MOULDINGS. While the Greeks usually relied upon refined profiles and delicate carving for effect, the Romans tended to enrich all possible surfaces with vigorous ornament. The sections of mouldings were bold, based generally on combinations of parts of a circle.

ORNAMENT. Greek models were copied extensively, the Acanthus and other foliage being conventionalized and applied to all possible mouldings. Ox-skulls and garlands, frequently carved in friezes, were derived from the sacrificial rituals of the Roman religion. Characteristic Roman ornament is shown in Fig. 44.

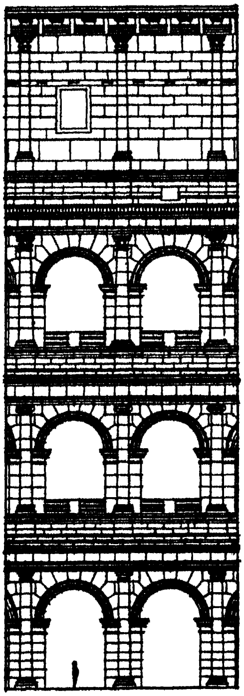


FIG. 43. THE COLOSSEUM, ROME
Part of the elevation

DECORATION. The decoration of wall surfaces was frequently carried out with marble panels, sometimes extending from floor to ceiling, and at others, as a dado, with stucco panels over. Vaults also were usually panelled or coffered, (Fig. 34), and richly painted and gilded. The walls of private houses were often decorated with paintings executed in *fresco, tempera, oil*, or *caustic*.

PAVEMENTS. Floors were frequently paved with marble in square, circular, and geometrical panels; these were in many cases taken up and used for a similar purpose in the early Christian churches, which will be referred to later. Mosaics of coloured marble and tiles were also used, generally in simple patterns, although remains of examples of a pictorial nature are to be seen in Pompeii and in museums.

POMPEIIAN DECORATION. This is one of the most important phases of Roman art. Its importance is largely due to the fine state of preservation in which it was found during the excavations in the eighteenth century; Pompeii, it will be remembered, was buried during the violent eruptions of Vesuvius in A.D. 79. Although based on Roman motifs, the work shows a delicacy and refinement which was, no doubt, largely due to the influence of the Greek element in the population of southern Italy. Of particular interest are the pictorial wall decorations in colour, and the delicate relief ornament to ceilings and vaults. Its influence is to be seen in the Adam style of decoration in England, and in French work of the same period.

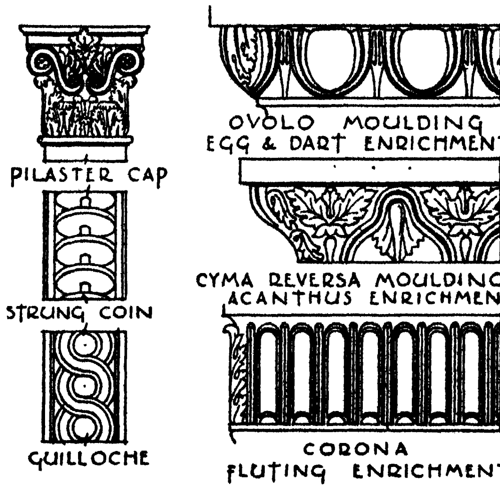


FIG. 44. ROMAN ORNAMENT

TOWN PLANNING

In the old established towns old buildings were cleared away from time to time to make room for fine civic centres, in which important buildings were grouped around an open space, already referred to as a Forum. The conjectural restorations by Piranesi, and by many Rome students, are a valuable and interesting source of study. Many of the ruins of towns founded by the Romans in their colonies, are evidence of their fine sense of civic beauty. One of the finest was probably the rarely mentioned little town of Tigmad, in North Africa, the ruins of which suggest that once the strategic lines of the fortifications were settled, the streets were laid out in a regular manner, and the important buildings provided with a setting worthy of their purpose.

Chapter IV—EARLY CHRISTIAN, BYZANTINE AND ROMANESQUE ARCHITECTURE

EARLY CHRISTIAN

ALTHOUGH there have probably been no events in the world's history more remarkable than the growth and spread of Christianity, it had little influence on architecture until legalized in A.D. 313 by the Roman Emperor Constantine, and established as the state religion in A.D. 323. During the first three hundred years of the Christian era worship was carried on more or less in secret, although some writers assert that a few churches were erected in Rome, only to be destroyed during the periodical persecutions of the new religion.

As soon as Christianity was recognized as the state religion, however, its strength became apparent, and there was a great demand for places of worship. It is probable that the pagan temples of the Romans were used at first, although they were soon found to be unfit for congregational worship and the new ritual.

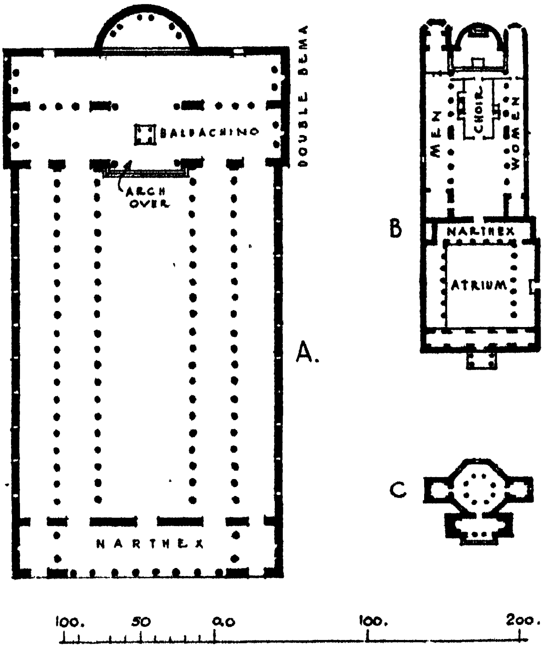
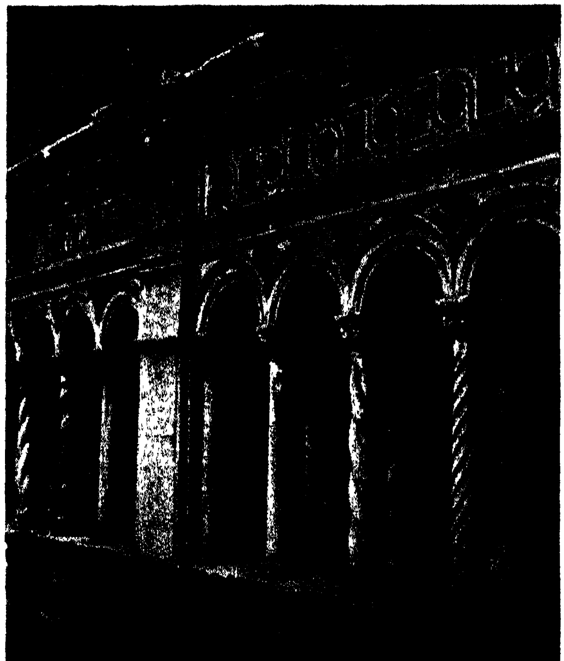


FIG. 45. PLANS OF BASILICAN CHURCHES

A = St. Paul Without the Walls, Rome
B = St. Clemente, Rome
C = Baptistery of Constantine, Rome



R.I.B.A., Gates Collection

FIG. 46. CLOISTERS, ST. GIOVANNI IN LATERANO, ROME

Basilican Churches. In their search for a suitable type of building, the early Christian builders appear to have found in some of the basilicas an arrangement consistent with their requirements. This was no doubt an important factor in the evolution of the churches, although it is interesting to speculate upon the possible rejection on sentimental grounds of buildings reminiscent of the baths and other places used for the debaucheries of the pleasure-loving Romans. The basilican type of plan, once adopted, was but slightly varied, and from it was evolved the plan form of the great mediaeval cathedrals of Western Europe.

Many of these early churches were built with materials obtained from the numerous vast Roman buildings which had fallen into decay, columns from various sources losing their bases, or receiving an additional one, in order to obtain a uniform height. It will be appreciated that there was little or no incentive to evolve new architectural forms when so much ready-made material was available, but the general arrangements of the churches are important as the seed from which the great Romanesque and Gothic styles were to grow.

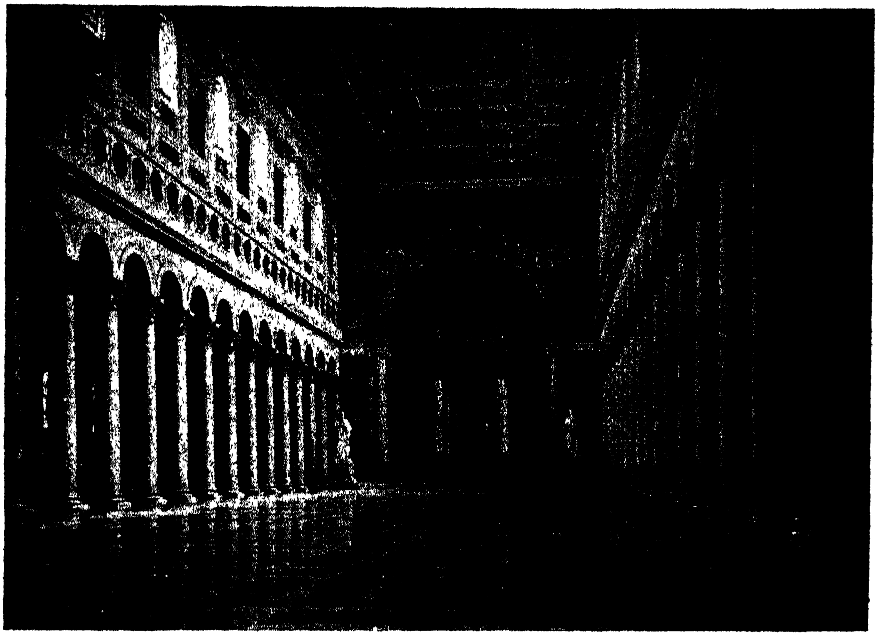


FIG. 47. ST. PAUL WITHOUT THE WALLS, ROME

The plans in Fig. 45 show the general arrangement of the basilican churches. In front was the *atrium*, or court-yard, surrounded by arcades or cloisters (Fig. 46), and in the enclosed space a fountain for ablutions. The atrium was later removed from most churches. At the entrance to the church was the *narthex*, an apartment where penitents and others not admitted to the church might see and hear parts of the services.

There were one or two aisles on each side of the nave, which was usually lighted by means of clerestory windows (see Fig. 47). It was the custom to separate the sexes, women sometimes being accommodated in a gallery over the aisles.

Various additions were made from time to time as the ritual became more elaborate. A *bema*, or transept, was introduced to provide space for extra altars and officiating clergy, while a space for the choir was enclosed by a screen, with an *ambo*, or pulpit, on either side. The main altar was sometimes placed in an apse, and a *baldachino*, or canopy, erected over it. The sanctuary was separated from the nave by a form of triumphal arch, which was decorated with paintings or mosaics of appropriate religious subjects.

Construction. These buildings were usually constructed in the manner of the Romans. Walls were of rubble or concrete, faced with brick, stone, or plaster. Openings were almost invariably spanned by a semi-circular arch, the lintel rarely being used. Roofs were usually supported on timber trusses of the King or Queen post type, ceiled in the manner previously referred to. Aisles and apses were frequently covered by a vault or semi-dome.

The exteriors of these buildings were very simple, the walling materials left bare, with bands of mosaic introduced to give richness to the west front and the cloisters.

Decoration. Internally, they were richly decorated. The nave arcade consisted of a series of arches on columns, although in some

cases the wall over was carried directly on the columns. Wall surfaces were beautifully decorated in rich colours and gold, usually in glass mosaic, depicting incidents in Christian history. The pavements reflected the richness of the walls, being formed of coloured marbles in geometric patterns (Fig. 47). Ceilings, formed of timber, were deeply coffered, and richly coloured and gilded.

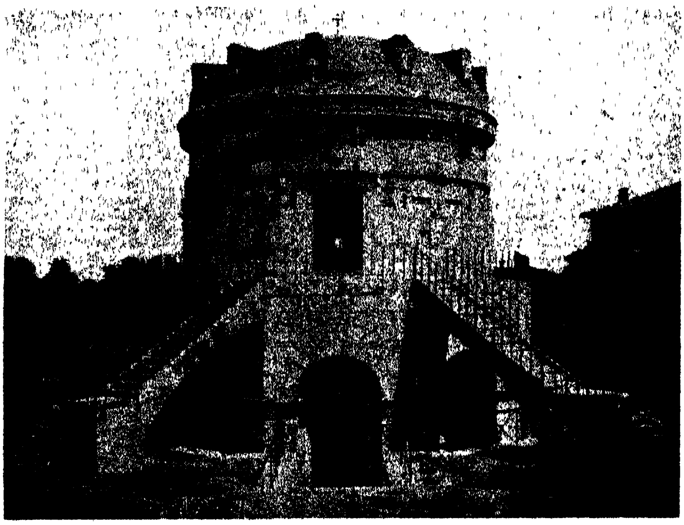


FIG. 48. THE TOMB OF THEODORIC, RAVENNA

Of the thirty or so basilican churches erected in Rome none remain, although a number were rebuilt at a later date on very similar lines. The church of St. Paul, Rome, although rebuilt during the last century, is almost completely identical with the original church. It is, as the plan indicates, about 400 ft. long, and is one of the largest churches existing. Many were built in other parts of the Roman Empire, together with baptisteries, buildings devoted solely to the service of baptism. There appears to have been one such building in each town, usually adjoining the atrium of a church ; it was isolated in this manner until the sixth century A.D., when the font was placed in the church itself. They were usually circular, or polygonal, on plan, with an inner circle of columns (Fig. 45).

Many tombs were erected, one of the most interesting, if unusual, was the tomb of Theodoric at Ravenna (A.D. 530). The roof of this building is formed from one block of stone, shaped in the form of a dome 35 ft. in span. The projections round the edge are handles used in hoisting this huge roof into position (Fig. 48).

BYZANTINE

It is believed that Byzantium, now known as Istanbul, was founded in the seventh century B.C. It became a Greek colony in the fourth century B.C., and, by virtue of its geographical position, grew in importance as a trading centre, particularly when it came under the domination of Rome.

Byzantine architecture is frequently considered in two distinct periods, but the differences are relatively slight. The first period extends from the time of the transfer of the capital from Rome, in A.D. 324, until the seventh century, when attention was fully occupied in resisting the invasions of the Persians, and, later, the Saracens. There were also internal disturbances due to the iconoclastic movement, a religious controversy which ended in the exclusion of sculptured figures from the Eastern Church. This was followed, in the ninth century, by a revival of building, when most of the existing churches of the Byzantine period were erected ; this is usually referred to as the second period, and is considered to extend to the occupation of Constantinople by the Turks in 1453.

Byzantine influence extended to Italy, Greece, and Russia, and may even be found in the architecture of Southern France. It became the recognized style of the Greek Orthodox Church, and remains so to the present day.

Chief Features. As with early Christian architecture, the buildings which remain are chiefly churches and baptisteries. There is no clear dividing line between the two styles, but the outstanding feature of Byzantine architecture is the dome. The ritual of the Eastern Church, although differing in some respects, did not involve any material differences in the planning of churches. A narthex was usually provided at the west end ; separate accommodation was also provided for women. Although one altar only was the rule, the east ends were frequently triapsal, the side apses being reserved for the clergy.

Domes. Before proceeding to consider the plans of these churches, it is necessary to understand the principles underlying the dominating feature of Byzantine architecture, the *dome*.

Although the dome had been employed by the Romans, they invariably used it over circular compartments, but in the works now under review, it was developed from a square or polygonal plan form, by means of *pendentives*.

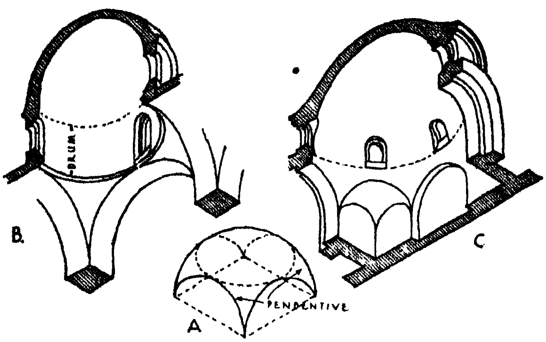


FIG. 49

A = The development of the pendentive
B = Triangular pendentives and dome raised on drum
C = Arch and semi-dome across angles forming pendentives

There are examples of this feature in eastern architecture of very early date, but the Byzantines were the first to employ it on a large scale. It will be seen in Fig. 49 (*A*) that the simplest development from the square to the circle on plan is that by means of curved surfaces, which are part of a hemisphere.

In many cases, particularly in later work, the square was first developed into an octagon by means of arches, or semi-domes, across the angles, above which a series of small pendentives, or a system of corbelling, produced the circle. There were three general types of domes. In the first, the dome and pendentives are part of a hemisphere (Fig. 49 (*A*)); in the second, a separate dome rises from the top of the pendentives (Fig. 49 (*C*)); while in the third, a cylinder, or drum, intervenes between the pendentives and the dome, giving greater height to the structure (Fig. 49 (*B*)). It will be appreciated that since the dome is composed of a series of horizontal rings, each of which is in equilibrium, it is logical to omit the centre portion and superimpose a separate dome, or cylinder (see Fig. 49 (*A*)).

With the exception of vaults and domes, Byzantine buildings were constructed in a very similar manner to those of the Romans.

Walls. Thick walls in the bigger buildings were frequently of concrete, faced with brickwork, while others were usually constructed of brick, or stone. The bricks were thin and the mortar-joints thick, so that it was necessary to allow the carcass of the building to settle and dry out before the internal decoration was commenced. Alternate courses of brick and stone, and bands or string courses of bricks laid diagonally, produced interesting exteriors, while, internally, walls were invariably covered with marble and mosaics.

Door and Window openings were usually semi-circular headed, the latter small, sometimes arranged in groups (see Fig. 51). In many cases they were subdivided into two or three lights by means of a central column, or mullion, with small arches over; a thin marble, or stone, slab was sometimes inserted, pierced to form a kind of tracery (see Fig. 50).

Columns were monolithic and usually of marble. Those used in many of the earlier churches were obtained from disused Roman buildings, but later they were quarried in the districts surrounding Constantinople, which was the marble working centre for the Roman Empire. It will be appreciated that the design of buildings was largely influenced by the size of column available.

Vaults and Domes. It will be remembered that Roman vaults and domes were usually constructed of concrete of great thickness, which, when set, exerted little or no thrust. Those of the Byzantines were very different. They were usually built of bricks, and of no great thickness.

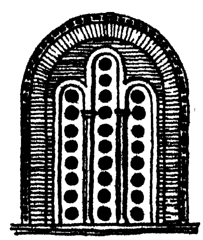


FIG. 50. A THREE-LIGHT WINDOW IN A CHURCH AT DAPPNI

In some cases, cut stone was used, and there are a few interesting examples where domes were formed with hollow earthenware urns, the use of which lightened the structure, and so reduced its thrust on the abutment. The brick, or stone, courses did not radiate from the centre of the dome, but from a point near the springing on the opposite side of the dome. In this way, it was possible to eliminate elaborate timber centering, one course being allowed to set

before the next was laid. It will be appreciated that these domes exerted a thrust, and the study of the plans of many of the churches will show how these thrusts were resisted by skilfully placed cross walls and semi-domes. In fact, the plans were largely determined by the construction of the crowning vaults and domes.

Buildings. Perhaps the finest example of

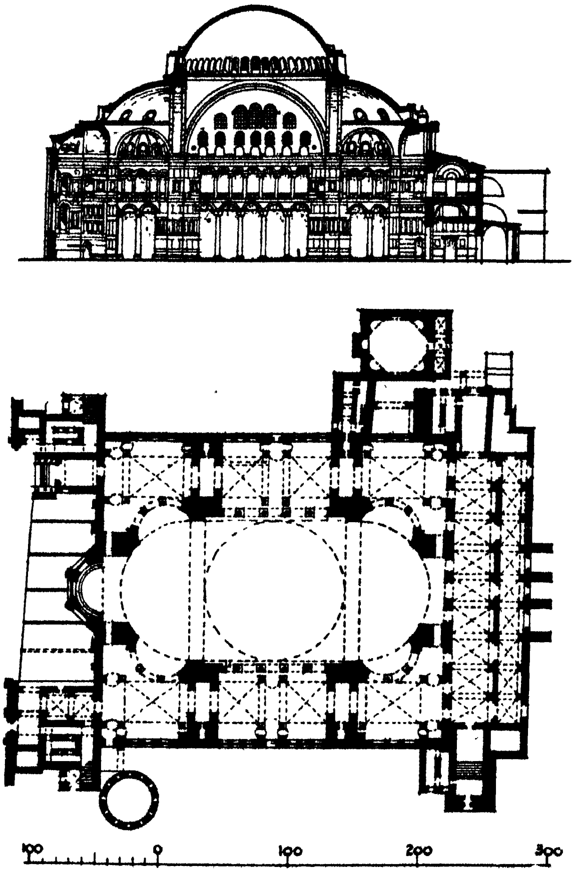


FIG. 51. ST. SOPHIA, CONSTANTINOPLE

Byzantine architecture is the great church of Constantinople. It was erected for Justinian to replace an earlier basilican church. Commenced in A.D. 532, it was completed in six years, a remarkable building feat. The great central space is about 265 ft. long by 107 ft. wide, covered by a great dome 107 ft. in diameter and two semi-domes. On either side are aisles 50 ft. wide, with galleries over, originally intended for women, and at the ends an apse and narthex respectively. The dome, which rises about 180 ft. above the pavement, is flatter than a hemisphere, and is carried by four great triangular pendentives, the largest of their

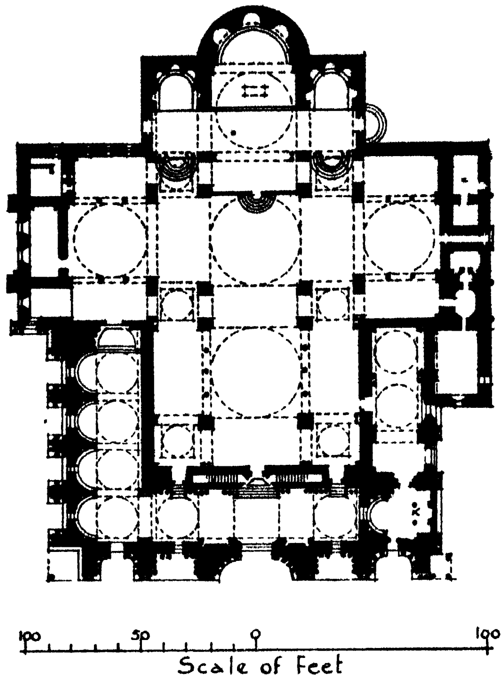


FIG. 52. ST. MARK, VENICE

kind in the world. These, in turn, are supported by huge piers, and the thrust of the dome is resisted by the semi-domes and by buttresses

FIG. 53. ST. MARK, VENICE

(see Fig. 51). The interior, with its rich marble walls and columns, wonderful mosaics and richly carved capitals, is one of the most impressive in the world.

Next in importance is the church of St. Mark, Venice (Figs. 52 and 53). It was commenced in A.D. 977 and completed the following century, the exterior columns and mosaics being added during the succeeding centuries. The plan is a Greek cross, with a dome over the crossing and over each arm of the cross. Those over the chancel and crossing are 40 ft. in diameter, the remainder being 33 ft. The interior is richly decorated with marbles and mosaics, and is not excelled even by St. Sophia.

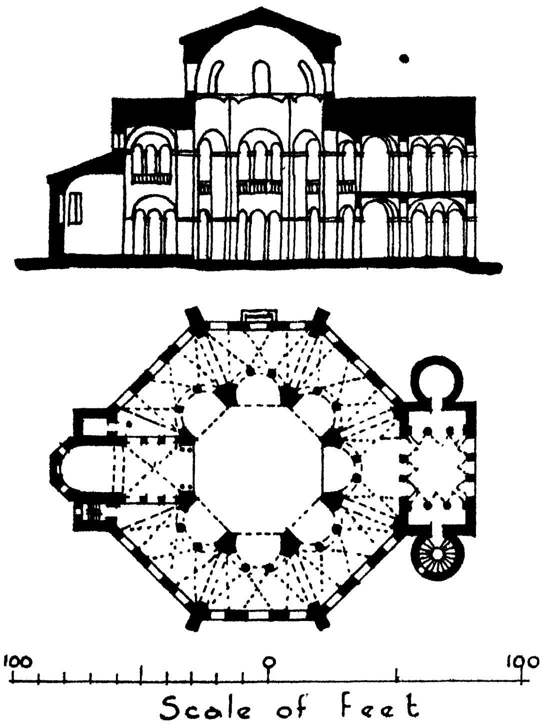


FIG. 54. ST. VITALE, RAVENNA; SECTION AND PLAN

Another interesting building is St. Vitale, Ravenna (Fig. 54); the constructional significance of the plan is worth study.

Decoration. A love of richness and colour was the dominant note in the decoration of these buildings. The lower parts of walls were lined with veneers of rich marbles, and the upper parts, together with the surfaces of the vaults and domes, were frequently covered entirely with glass mosaics, depicting Christian symbolism. The subject matter was executed in colours on a background of gold.

Mouldings were rarely used, simple string courses being introduced to mark structurally important points, such as the springing of the dome. These were sometimes carved (Fig. 55), but the craftsmanship was usually very poor. The capitals are interesting and of great variety. Many were based on the Roman, Ionic, and Corinthian types of capital, and these were often provided with a deep abacus, known as a *dossoret.* Perhaps the best were those specially designed to support the springing of the arch,

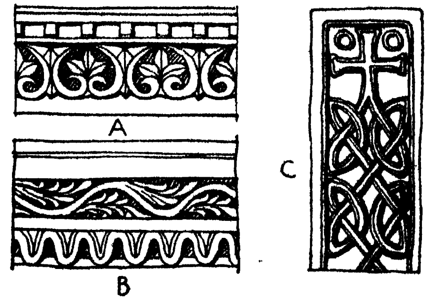


FIG. 55. BYZANTINE CARVING

A = Anthemion frieze
B = Vine ornament
C = Interlace panel

which was larger than the column. They were convex in outline and delicately carved, a sharpness of detail being secured by the drilling of the sinkings between the leaves, etc. (Fig. 56).

Apart from its richness and splendour in decoration, Byzantine architecture must always

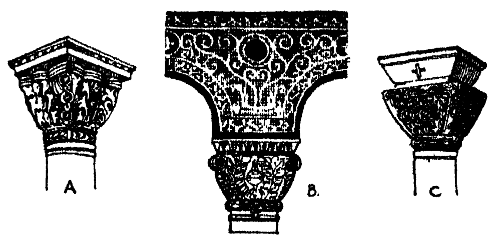


FIG. 56

A = Capital from St Mark, Venice
B = Capital and mosaic spandrils from St Sophia, Constantinople
C = "Basket" capital and "Dossoret" from St. Vitale, Ravenna

be studied for its straightforwardness in the solution of building problems. A thorough understanding and appreciation of the structural basis of the many beautiful plans of these early churches will be an invaluable asset to the modern student of architecture.

ROMANESQUE

The influence of Roman art had spread throughout the Empire, and however much the

works of the Romans in the colonies had been despoiled, or had fallen into decay when the Roman legions were withdrawn, the seed thus sown must be accepted as the real beginning of Western European architecture. For convenience, however, it is customary to consider the period in question to extend from the date of the election of the first of the Frankish kings in

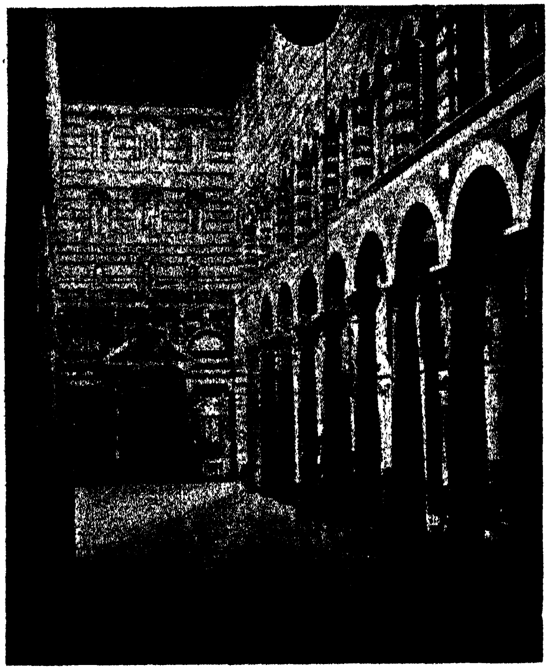


FIG. 57. PISA CATHEDRAL
(Interior, the West end)

Italy, Charlemagne, in A.D. 799, to the general adoption of the pointed arch in the twelfth century.

Very little building was done before A.D. 1000. This is easily understood, for history shows that during the years known as the Dark Ages, almost the whole of Europe was in a state of chaos. It will be recalled that it was popularly believed that the world would come to an end in the year A.D. 1000, and the progressive arts of peace were more or less abandoned. With the millennium safely passed, conditions became more settled, and many of the nations of Europe came into existence as self-governing states.

Throughout, however, the Church had thrived, and remained the one stable influence of the people. Monastic orders were founded, and the clergy became the scholars of the times. They fostered the arts and crafts, and were responsible for the building of many monastic establishments, which were frequently the beginnings of towns. Until the twelfth century, in fact, learning was the monopoly of the Church ; how natural, then, that the buildings erected during this period were, for the most part, of a religious character.

Although Romanesque architecture is said to have grown out of Roman art, so many factors influenced its development in the various parts of Europe that it was inevitable that there were many phases or sub-styles, the history of which is both lengthy and involved. As has been pointed out, Rome was the centre from which Christianity spread, and builders naturally turned to that city for inspiration ; but Rome was far distant from many of the countries of Western Europe, and its influence slight. Since all the important buildings were of an ecclesiastical nature, there was a certain similarity between the various national phases of the style ; but while in Italy there were many Roman and Early Christian buildings to give inspiration, in many of the one-time Roman colonies there were relatively few remains, and these were frequently little more than heaps of stones. It is, therefore, convenient in this brief history to consider the development in Italy separately, for there the traditions of the Early Christian and Byzantine builders were carried on with little variation.

Italian Romanesque. Churches continued to be modelled on the Basilican type, already described. Transepts were increased in size, and the east end extended, producing a pronounced cruciform plan. Pisa Cathedral, Fig. 57, is one of the best examples of the style in Central Italy. Internally, the arcading and coffered ceiling are reminiscent of the earlier churches. Externally, the building owes much to the richness given by rows of " blind " arches and the use of coloured marbles, but it does not represent any serious advance in the logical evolution of a style. The dome over the crossing is a later addition. The Campanile (known popularly as the Leaning Tower) is to be seen in Fig. 58. Bell towers were erected near many of the bigger churches in Italy.

In the north, Byzantine influence was very strong, for not only were Ravenna and Venice important centres in the development of that style, but the latter town was still linked with the east by trade. A number of churches were

built, however, which closely followed the Basilican form, but the introduction of vaulting led to the reduction in width of the nave, and certain modifications to the supports; instead of slender columns, sturdy piers became necessary, consisting in section of a cluster of members arranged to support the various arches

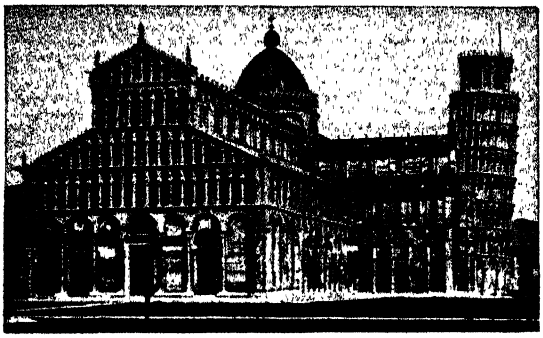


FIG. 58. PISA CATHEDRAL (A.D. 1063–1092)
(From the South-west)

and ribs over. Externally, these churches were much simpler than those in Central Italy, owing to the general use of brickwork.

In the south and in the island of Sicily, the successive influence of Byzantines, Mohammedans, and Normans contributed to the character of the architecture. One of the finest buildings was erected under the rule of the latter—the

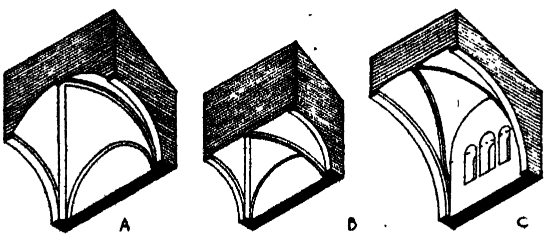


FIG. 59. VAULTING DIAGRAMS

cathedral at Monreale, in which Byzantine capitals and colour decoration of a Mohammedan character are to be seen.

In those countries west of Italy little progress was made during the first ten centuries of the Christian era. After the millennium, however, a period of great building activity ensued, which was to culminate in the great Gothic style of the thirteenth and fourteenth centuries.

The work of each country has distinctive features, but certain similarities result; firstly, from the general adherence to the Basilican plan, and, secondly, from the general adoption of vaulting.

Vaulting. It is generally accepted that vaulting was introduced to meet the need for a more lasting and fire-resisting roof than the timber form. The earliest vaults were constructed in the Roman manner, in which the stone was of consistent thickness throughout. The barrel vault was not used to a great extent, for it was open to the objections that it did not permit large windows in the upper part of the nave wall, unless it was very high, and also that, since its load was continuous, it was impracticable to superimpose it over an arcade. This led to the introduction of cross or intersecting vaults, which were more satisfactory in that they permitted large windows in the side walls, and concentrated their loads on the points best able to support them. The next step was the introduction of "rib" vaulting, in which ribs, or arches, were thrown across from pier to pier, both transversely and on the face of the wall, thus forming a framework which supported a vault of thin stone, known generally as a *severy*, or as *infilling*. This was followed by the use of a diagonal rib, which divided each bay up into smaller compartments. It will be appreciated that the shape of the rib became an important consideration, and two methods of arrangement are evident. In the first, used

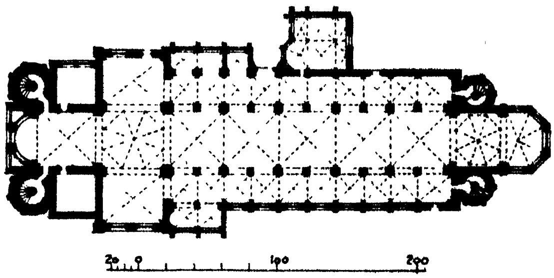


FIG. 60. PLAN, WORMS CATHEDRAL

extensively in France, all of the ribs were segments of the same circle, or semi-circular; the diagonal thus had much greater height than the remainder, and each bay was in consequence domical (Fig. 59 (*A*)).

In the second method, used generally in England, in order to produce a level ridge, the ribs were all semi-circular, but those in the shorter directions were stilted so as to produce a uniform height; in other cases, a segmental arch was

employed across the longer spans for the same reason (Fig. 59 (*B*)). This was found to be unsatisfactory in two ways. First, the diagonal rib in square bays assumed too great a span; secondly, the stilting necessary to ribs across the narrower spans in rectangular bays became

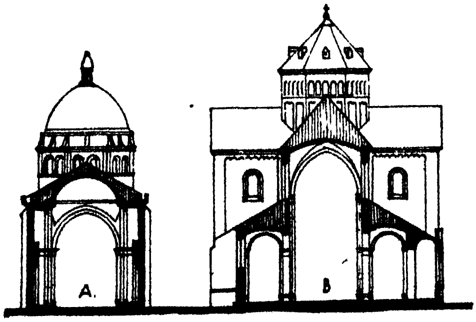


FIG. 61. SECTIONS THROUGH THE NAVE
A = Angoulême Cathedral. *B* = Worms Cathedral

excessive (Fig. 59 (*C*)), and produced weak structures and distorted groins. These were two of the factors which led to the adoption of the pointed arch, the feature which is most characteristic of the Gothic style. This feature

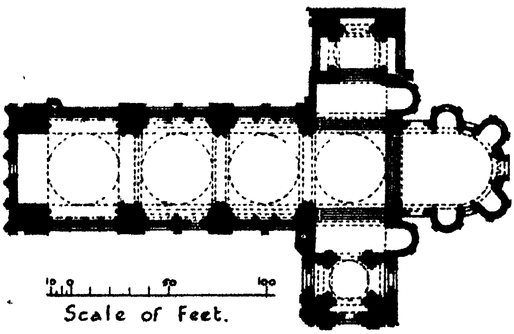


FIG. 62. PLAN, ANGOULÊME CATHEDRAL

will be dealt with later, when the great influence which vaulting had upon the general design of buildings will be discussed.

German Romanesque. The close relationship between Germany and Northern Italy, both territorially and politically, is to be found also in the phases of Romanesque architecture in those two countries, although vaulting was used much more extensively in the former. Transepts are frequently found at the west as well as the east, and the choir is usually apsidal. In the arrangement of the piers, the spacing is adjusted to suit the vaulting, two bays in the aisles being provided to each one in the nave (Fig. 60).

Internally, Italian influence is sometimes to be seen in the painted and mosaic decorations to wall surfaces, though the general use of coloured bricks and stone led to a more subdued treatment. Towers were frequently provided over the crossing and at the east and west ends, pro-

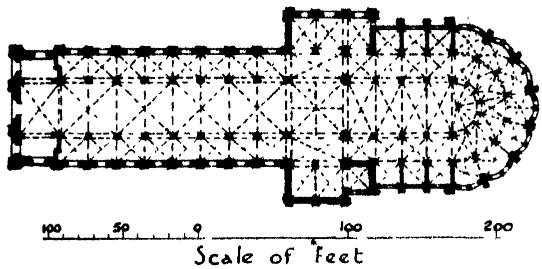


FIG. 63. PLAN, ABBAYE-AUX-HOMMES, CAEN

ducing interesting exteriors. Roofs were naturally rather steeper than those found in Italy, while those on the towers were particularly steep, and formed spires, which were a feature of the style.

French Romanesque. Of the many factors which appear to have contributed towards the

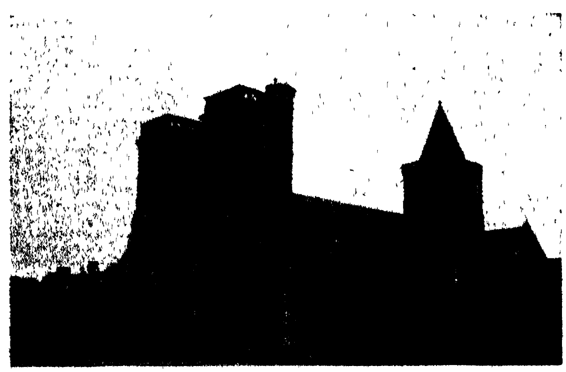


FIG. 64. ABBAYE-AUX-DAMES, CAEN
(From the South-west)

differences to be found in the architecture in various provinces in France, it is probable that none was so important as the contact through trade between the ports in the South with Venice and the East. At Périgueux, the church of St. Front bears a striking resemblance in plan to St. Mark's, Venice, both the plan and the domes over being very similarly arranged. Internally, however, there is none of the rich decoration to be found at Venice. Angoulême Cathedral is another example in which Byzantine

influence is to be seen in the arrangement of domes on pendentives over the four bays of the nave (Figs. 61 and 62). Other buildings in the south possess many features which reveal the influence of the many remains of Roman buildings in the district.

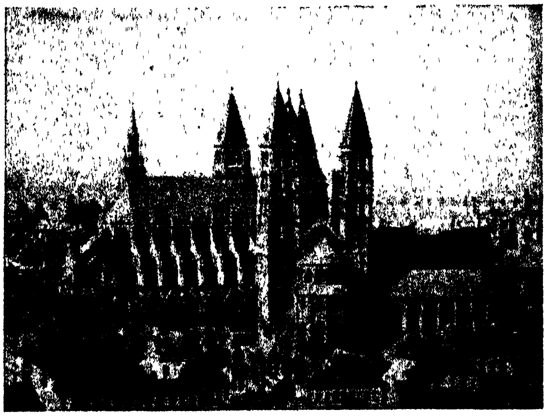


FIG. 65. TOURNAI CATHEDRAL
(From the North)

In Central France and the Northern Provinces are to be found churches which constitute very largely the beginnings of the Gothic style. In plan, they were very similar to those already referred to, having an aisle in either side of the nave; and the spacing of piers was usually adjusted so that the bays of the nave were square, there being two in the aisles to each one in the nave (Fig. 63). In the city of Caen are to be found some of the best examples. The plan of the Abbaye-aux-Hommes (St. Etienne), commenced in A.D. 1066 by William the Conqueror, shows the typical arrangement, but here the vaulting over the nave shows an advance in the use of the sexpartite vault, which will be referred to later. The east end is of later date than the remainder; it is formed by the continuation of the aisle around the apsidal end of the choir, and the addition of chapels to each of the bays; it is known as a *chevêt*, a feature chiefly found in French cathedrals, although there is a similar arrangement in Westminster Abbey. Another fine building in the same city is the Abbaye-aux-Dames (La Trinité), Fig. 64.

One of the finest churches of its kind in Europe is the cathedral at Tournai, in Belgium. See Figs. 65 and 66. The nave and apsidal transepts are Romanesque, but the choir and

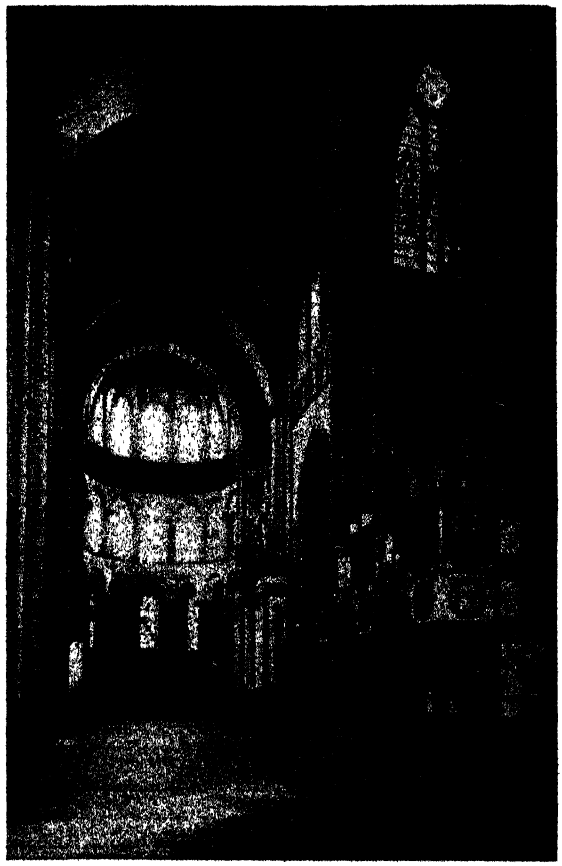


FIG. 66. TOURNAI CATHEDRAL
(The North Transept)

chevêt are of fourteenth century Gothic. The towers are typical of the style.

English Romanesque. In order that the history of the evolution of Gothic architecture in England may be told in a complete story, the Romanesque work in England will be dealt with in the next chapter.

Chapter V—MEDIAEVAL ARCHITECTURE

ROMANESQUE and Gothic architecture are often referred to collectively as *mediaeval* architecture. This has much to commend it, since the evolution of the styles of the period involved was continuous; but, as will have been appreciated from the last chapter, so many and various phases are included that further distinction is advisable. The term *Gothic* is generally accepted to include those styles which grew out of the Romanesque in Western Europe, of which the pointed arch is a characteristic feature. The word itself has no particular significance; it was applied with contempt by the enthusiastic followers of the Classic Renaissance, who considered Gothic architecture to have been introduced by barbarians.

FIG. 67. SALISBURY CATHEDRAL FROM THE NORTH-EAST

The consideration of the architecture preceding the Gothic in England has been reserved in order that evolution might be followed more closely. Space will not permit of more than a brief survey of the salient characteristics of English mediaeval architecture and a few typical examples of contemporary work on the Continent. In any case, once the fundamentals of a style are appreciated, the actual buildings are the best sources of information, and no country offers the student more examples of the monuments of the Middle Ages than our own.

The architecture of England prior to the Norman Conquest is known as *Anglo-Saxon*. That which followed has been variously classified by the many writers on the subject, a subdivision into the four following styles being the most common: *Norman* (or *English Romanesque*), *Early English*, *Decorated*, and *Perpendicular*. The periods given to each vary, and, in any case, architecture was in a constant state of transition, and progress throughout the country was far from consistent, but the following may be taken as an indication of the periods during which the more characteristic features were developed: 1066–1175, 1175–1275, 1275–1350, and 1350–1550. The names given to the periods are in some cases vague and misleading, but some nomenclature is necessary, and that given will be found in general use. It must be

appreciated that subdivision concerns architectural characteristics rather than date of execution.

Before proceeding to the consideration in detail of the various phases of this style, it will be well to discuss the general arrangement of the cathedrals, which were the most important buildings of the period.

Planning. Salisbury Cathedral, Fig. 68, is frequently accepted as a typical example; its general disposition is the more straightforward because, unlike other cathedrals, it was almost entirely built in a relatively short time (A.D. 1220–1258), while the others were added to and altered in various periods.

The plan was usually cruciform and the building was orientated, the *nave* to the west and the *choir* to the east, both being long and narrow, the length of the former being sometimes as much as six times its width. *Transepts* were very pronounced, and in some cases were duplicated to a smaller scale on the eastern arm of the cross. Over the *crossing* was the central tower, sometimes surmounted by a spire, as at Salisbury, Chichester, Lichfield, and Norwich. At York, windows were provided in the tower, which is usually referred to as the *lantern*. There was usually a single *aisle* on either side of the nave and choir, and in some cases to the transepts. The east end was square in most cases, as at Salisbury; at Norwich and at Westminster Abbey it took the form of a *chevêt*, already referred to. Behind the choir was placed a *chapel* dedicated to the Virgin Mary, usually known as the *lady chapel*, while other *chapels chantries*, and *shrines* dedicated to minor saints and patrons were situated elsewhere, usually in the east end of the building. Cathedrals were frequently attached to monastic establishments, in which case the *cloisters* served as a means of communication between the principal buildings of the monastery, such as *refectory*, *kitchens*, *dormitory*, and *chapter house*. The latter, the only one of these which remains in any number, was normally octagonal, with a central pillar to support the vault. The cloisters were usually placed on the most sheltered side of the cathedral. At Salisbury the introduction of cloisters was rather due to tradition than to usefulness, since this was not a monastic church. The west front was usually treated in an imposing manner; in some cases, as at York, Ripon, and Canterbury, towers were added. Minor porches were frequently introduced in more sheltered positions.

NAVE ARCADE. The upper part of the wall of the nave was carried on a series of arches, known as the *nave arcade*, usually ranging with the vaulting over the aisle.

TRIFORIUM. Above this arcade was frequently a further range of openings into the roof space over the aisle; this is known as the *triforium*, sometimes called a *blind story* when there are no windows to the open air. In some of the taller cathedrals a definite story was introduced, as at Westminster and Notre-Dame, Paris.

CLERESTORY. In the upper part of the nave wall was a range of windows called the *clerestory*, which was the chief source of light.

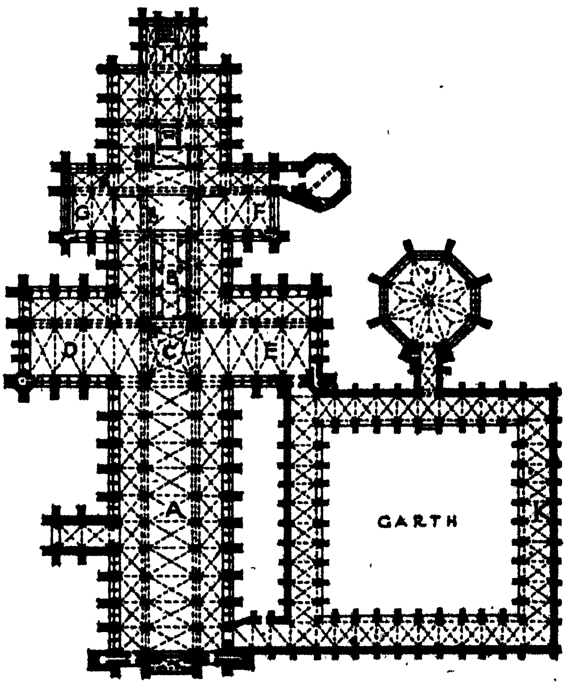


FIG. 68. PLAN—SALISBURY CATHEDRAL.

A = Nave	*F* = South-eastern transept
B = Choir	*G* = North-eastern transept
C = Crossing	*H* = Lady chapel
D = North transept	*J* = Chapter House
E = South transept	*K* = Cloisters

Constructional Problems. Although ritual and custom determined the general disposition of the plans of the great cathedrals, the requirements of construction were always the chief factors in the evolution of the style, and it will be readily appreciated from the study of the sections in Fig. 69 that the construction of the vaults over the naves, and the counteracting of their thrusts, was the great problem which

confronted the builders. In fact, the history of Gothic architecture is very largely that of the development of systems of vaulting and buttressing. In Norman work it was the practice to build thick walls and piers with a facing of squared stone and a filling of rubble, but with the desire for more extensive and loftier buildings other methods were found necessary, not only to ensure more reliable structures, but to economize in materials and transport. Walls and piers were reduced, and buildings resolved themselves into skeletons of masonry, consisting of *vaults*, *piers*, and *buttresses*. Besides their vertical load, vaults exert an outward pressure, and in earlier work thick walls were necessary to resist this force which threatened to overturn them. The use of the buttress, or short return wall, at right angles to the thrust, relieved the wall of the lateral pressure, and in consequence a smaller pier, or wall, was sufficient to carry the simple vertical weight. The existence of aisles at the sides of the nave introduced fresh difficulties, for buttresses could not be carried down on the nave wall. They were, therefore, placed along the outer walls of the aisles, and the thrust of the vault carried across the intervening space by means of *flying buttresses* (Figs. 69 and 70). These were in some cases concealed beneath the roof of the aisle, but the great height of the nave vault often made it necessary to introduce them above the aisle roof. It will be obvious that only through an understanding of the constructive principles of the buttress were the mediaeval builders able to construct vaulted ceilings at such great heights.

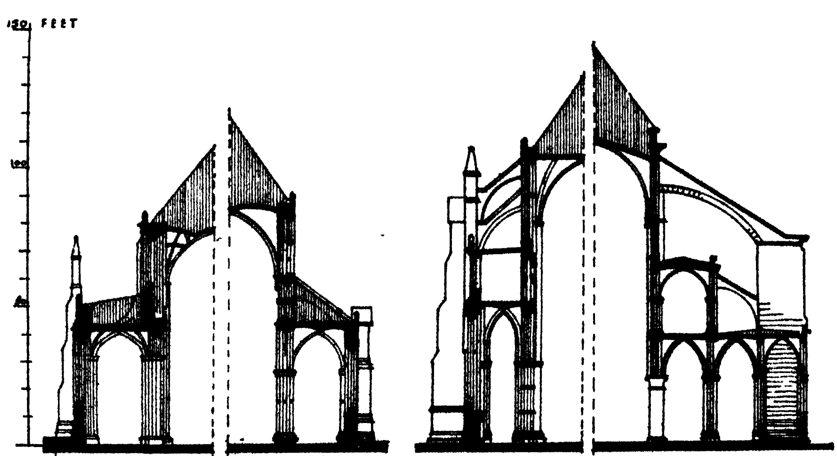


FIG. 69. SECTIONS THROUGH THE NAVES OF CATHEDRALS
A = Winchester
B = Salisbury
C = Westminster Abbey
D = Notre-Dame, Paris

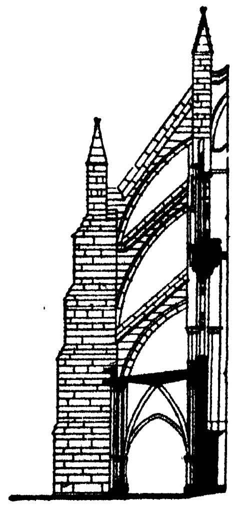


FIG. 70. FLYING BUTTRESSES, WESTMINSTER ABBEY

Gothic Vaulting. Two of the difficulties met with in the use of semicircular and segmental forms in Romanesque vaulting were the sometimes excessive span of the diagonal rib in square bays, and the distortion resulting from the use of stilted ribs across the shorter spans. In the former case, the introduction of a further rib across the intermediate piers helped to support the diagonals, and formed the *sexpartite vault*, but although this system was employed generally in France until the end of the twelfth century, there are only one or two examples in England. Here, the oblong bay was favoured, and the second difficulty referred to disappeared with the use of the pointed arch, which made it possible to give satisfactory curvature to arches and ribs of any required span and rise. The simplest form of vault was the *quadripartite*, with transverse and diagonal ribs which subdivided each bay into four cells (Fig. 71A). The courses of stone forming the infilling (usually of the lightest material available, about 4 in. to 8 in thick) were at first laid on the back of the rib, but later the ribs were rebated; see Fig. 72A and B. Two general systems of arrangement of the infilling appear to have been in use; they are known as English and French, but examples of the latter are to be seen in this country. In France it was the custom to

arrange the courses parallel to the ridge of the vault, while in England they were set out at right angles, either to the diagonal rib or to a line bisecting the angle formed by the diagonal rib and the wall or transverse rib. This latter method produced an irregular junction at the ridge, and was not as strong as the French method.

RIDGE RIBS. Some writers are of the opinion that, in order to hide this irregular junction a

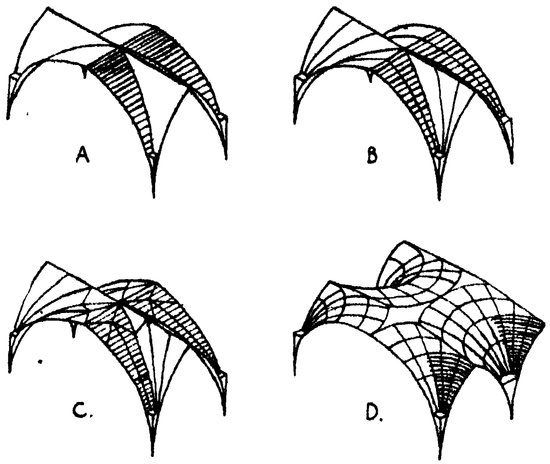


FIG. 71. VAULTING DAIGRAMS

A = Quadripartite vault
B = Tiercerons
C = Tiercerons and liernes
D = Fan vault

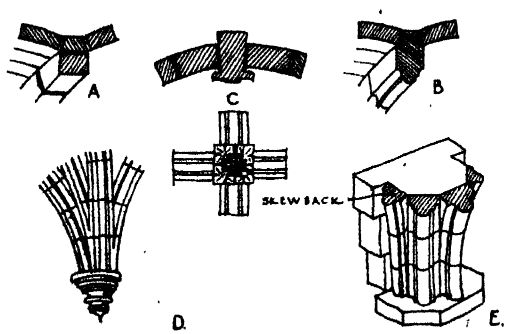


FIG. 72. VAULTING DETAILS

rib was introduced at the ridges, but it seems more probable that this resulted from the desire to mark this change in the surface of the vault.

TIERCERONS. Intermediate ribs were next introduced which reduced the width of the compartments or cells; see Fig. 71B.

LIERNE RIBS. To further stabilize these intermediate ribs, and for decorative purposes, no doubt, short ribs known as *liernes* were introduced; see Fig. 71C. They did not spring from the vaulting shaft, but were arranged so as to connect the various ribs together. A few arrangements are given in Fig. 73. Although the mitres at the intersection of ribs were occasionally worked out completely, the junctions were, as a rule, masked by a *boss* (Fig. 72C) or keystone against which the ribs abutted, the underside of which was often

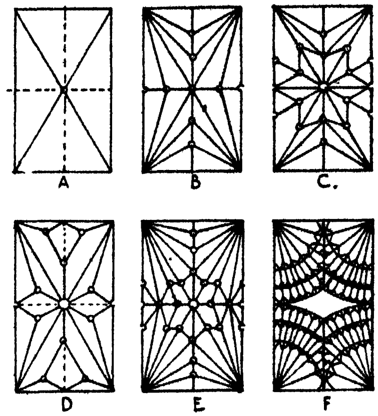


FIG. 73. VAULTING—PLANS OF BAYS

beautifully carved. With the increasing number of ribs, the cells became very small and of minor importance. In fact, rib and panel were soon to be worked on one piece of stone, and the rib lost its structural significance. It will be seen, from Fig. 73F, that the ribs radiating from the shaft take the form of a fan, and this forms the basis of the *fan vault* (Fig. 71D), the earliest example of which is that in the cloisters of Gloucester. Fine examples are to be seen at Henry VII's Chapel, Westminster, St. George's Chapel, Windsor, and King's College Chapel, Cambridge.

In Norman work, ribs were independent from the springing upwards, but later, the increase in their number and the relative smallness of the piers made this impossible. They were partly merged one into another at the springing and formed from one stone, rising in this way until each rib was complete, when a skewback was formed and the ribs continued separately (Fig. 72E). These bottom courses had horizontal beds, and are collectively called the *tas-de-charge*.

In some cases, the shaft from which the vaulting springs was taken up from the pier supporting the nave arcade, while in others it sprang from a *corbel*, a small example of which is illustrated in Fig. 72D.

Although the development of vaulting and the general constructional arrangements which form the basis of mediaeval architecture were more or less consistent throughout the country, the less important features were produced in very great variety, but the outstanding characteristics of the various phases were as follow.

Anglo-Saxon Architecture is considered to date from the arrival of the Anglo-Saxons in A.D. 449 to the Norman Conquest (A.D. 1066).

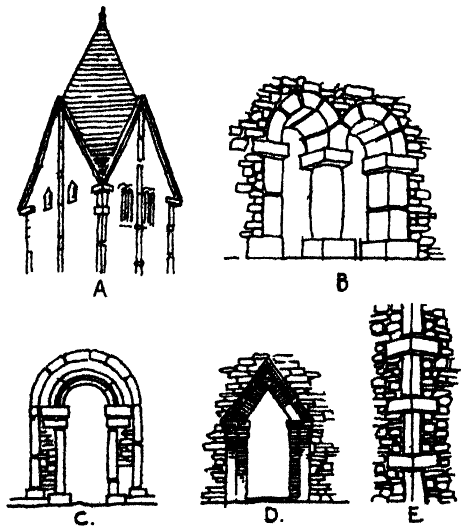


FIG. 74. SAXON DETAILS

A = Spire at Sompting, Sussex
B = Window at Worth, Essex
C = Doorway in stone
D = Doorway in brick
E = "Long and short work" in quoins

Although relatively little advancement was made in the art of building during this period, it is unreasonable to dismiss it as valueless. Of the many factors which contributed towards the building up of a style, the following were the most important. The remains of the buildings erected during the Roman occupation undoubtedly provided many examples of masonry construction, but were chiefly valuable in the provision of ready-worked materials. The Saxons no doubt destroyed many of the buildings they found on their arrival, and their works similarly suffered at the hands of the Danish invaders. The arrival of Augustine's mission in A.D. 597 brought the influence of Early Christian Rome to England, while the establishment of powerful monastic settlements resulted in an influx of Continental ideas. Few examples of Saxon work remain, due not only to the destructive agencies referred to, but also to the use of timber for so many buildings; many were probably pulled down later to make way for bigger and better buildings. A series of typical Anglo-Saxon features is given in Fig. 74.

Norman Period. Despite the influence of the invaders from Normandy, who not only obtained civic and military control of the country, but took the important church offices, the Saxon traditions were not obliterated, but rather became welded to those of the Normans. It was inevitable, however, that there should be

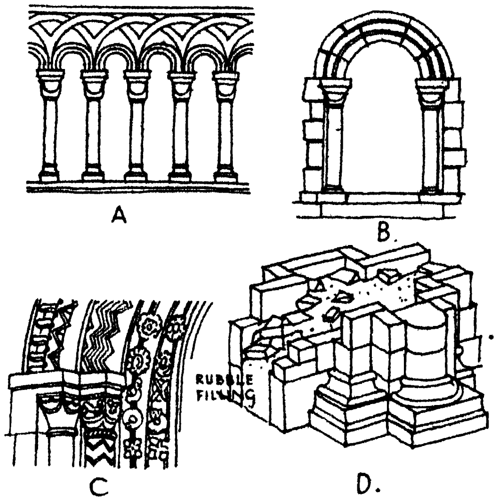


FIG. 75. NORMAN DETAILS

A = Arcading at Canterbury, showing intersecting arches
B = Niche at Leigh, Worcestershire
C = Enrichment to doorway at Iffley Church, Oxon
D = Norman walling

many similarities between the architectures of Normandy and England. Many of the great cathedrals were commenced during this period, and very extensive works are to be seen at Ely, Winchester, Peterborough, Norwich, Durham, Gloucester, Hereford, and St. Albans, while in London there are excellent examples at St. Bartholomew's, Smithfield, and the Chapel of St. John in the Tower. The plans of these buildings indicate substantial developments of the simple form usual in earlier work; the nave was lengthened and transepts introduced, while many have a tower over the crossing. Walls were very thick; columns were massive, either circular or a simple cluster in section; ornament and mouldings were very simple, although some later examples show great richness through the carving of the mouldings on deeply recessed door openings. Typical features are illustrated in Figs. 75 and 75A. Vaulting was employed in a number of cases, generally similar to that

referred to in Chapter VI, but the presence of vaulting of later date in many of the cathedrals enumerated above suggests that these

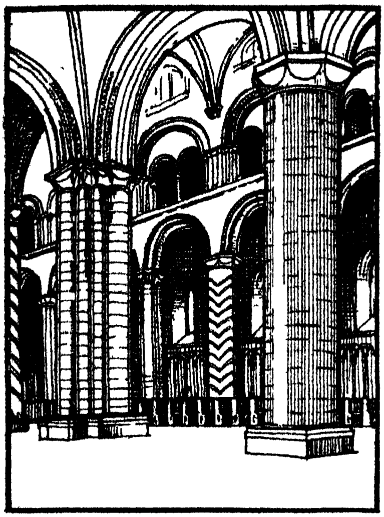


FIG. 75A. DURHAM CATHEDRAL—THE NAVE

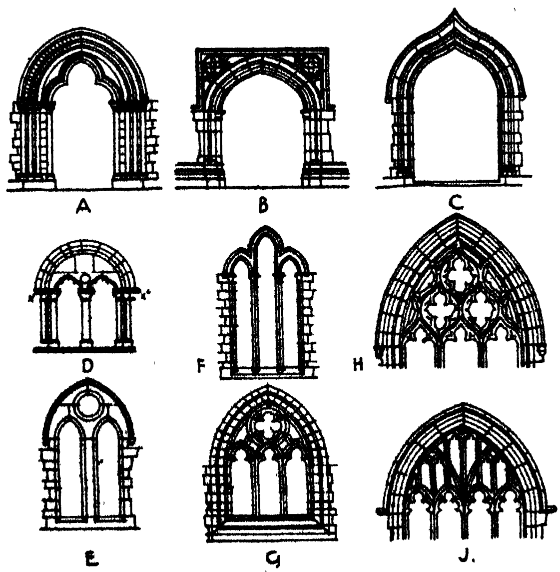


FIG. 76. DOORS AND WINDOWS

A = E.E. door
B = Perpendicular door
C = Ogee arch
D = Early English triforium
E = E.E. window with plate tracery
F = E.E. triple lancet window
G = Window with geometrical tracery
H = Curvilinear tracery
J = Perpendicular tracery

buildings originally had open timber roofs, with sometimes a flat boarded ceiling.

It is not possible here to do more than refer to the large number of castles erected during the twelfth century, built both as residences for the nobles and as military posts. Examples will be familiar to all, although restorations and later additions have considerably altered many of them.

Early English Period. Norman traditions were maintained, and although the pointed arch was adopted for vaulting and then for windows, it was some time before the semicircular arch disappeared altogether. Windows were at first small, largely because of the rarity of glass, but jambs were splayed internally so as to secure the greatest possible light. Characteristic windows were tall and narrow with sharply pointed arches, known as *lancets*, from which the style is sometimes named "lancet." They were

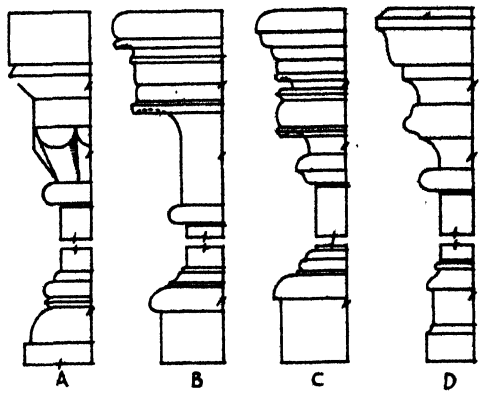


FIG. 77. MOULDED CAPITALS AND BASES

A = Norman
B = Early English
C = Decorated
D = Perpendicular

arranged in groups of two, three, or five (Fig. 76F); and, later, they were contained in one arch and the upper parts of the openings formed by piercing a slab of stone. This early form of tracery is known as *plate tracery* (Fig. 76E). The upper parts of the openings were sometimes subdivided into "foils" by means of small projections known as *cusps*, arrangements of three, four, and five compartments being known as *trefoil*, *quatrefoil*, and *cinquefoil*, respectively.

Door openings were deeply recessed and richly decorated (Fig. 76A). Piers were less massive than the Norman, and consisted generally of a central pier with small detached shafts, sometimes of polished marble as at Westminster. Capitals were either moulded (Fig. 77B), or enriched with carved foliage of a conventional character (Fig. 78A). Piers had simple bases which were sometimes raised on square plinths.

Walls were usually less massive than the Norman, both owing to the greater use of

dressed stone, and the increased importance of the buttresses. These were arranged with weathered off-sets, and sometimes a small gable at the top.

Mouldings were elaborate, consisting of alternating rolls and deep hollows. Foliage was stiff and conventional in character. The dog-tooth was the most used form of running ornament. This is regarded by many as the finest phase of

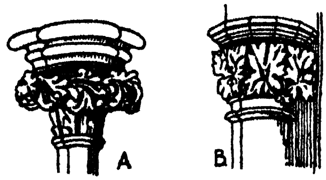


FIG. 78. CAPITALS

A = Early English *B* = Decorated

Gothic architecture, notable for its delicate and restrained detail and purity of line and form. The following are among the best examples: Westminster Abbey, Salisbury Cathedral, Lincoln (the nave), and Lichfield.

Decorated Period. This title is hardly appropriate, for the style which followed was also very ornate. It was probably so named because

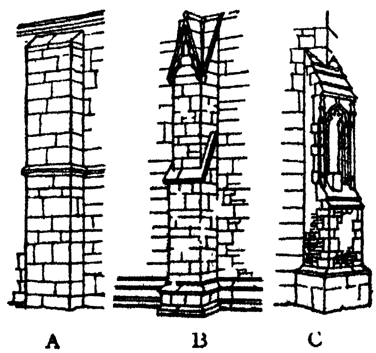


FIG. 79. BUTTRESSES

A = Norman *B* = Early English *C* = Diagonal buttress at All Saints', Colchester

of the richness of windows during the period which, with the growing popularity of stained glass, became very much larger. They were relatively wider, the arches being struck generally within an equilateral triangle. They were subdivided by mullions into two or more lights, and the upper parts filled with tracery of geometrical patterns with clearly defined cusps. Instead of being pierced in a slab of stone, the pattern was formed with bars of similar section to the mullion, and is known as "bar-tracery" (Fig. 76G). The style is sometimes named *geometrical*, after this form of tracery. In the later part of the period, the tracery was more graceful and flowing in character and is sometimes referred to as *curvilinear* (Fig. 76H). Door openings were not so deeply recessed as previously, but still highly decorated.

Piers did not change substantially, but the shafts were incorporated instead of being

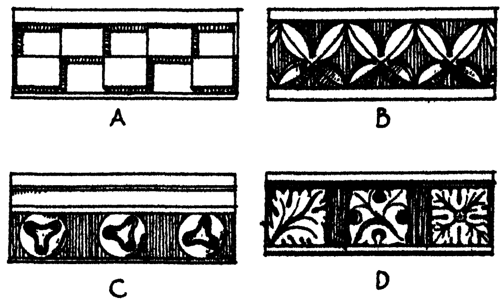


FIG. 80. ENRICHED MOULDINGS

A = Norman (*billet*) *B* = E.E. (*dog-tooth*) *C* = Decorated (*ball-flower*) *D* = Perpendicular (*cove with patera*)

detached. Capitals were still moulded in a similar manner to those in the former period, but when enriched, the carving was a more

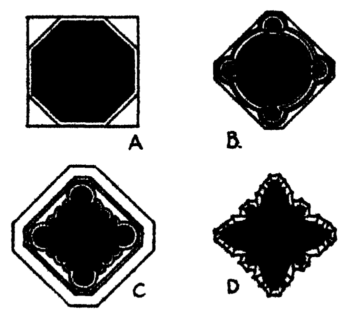


FIG. 81. PIERS

A = Norman *B* = Early English *C* = Decorated *D* = Perpendicular

realistic representation of oak, ivy, and vine leaves. Bases to piers had less spread, but were more elaborately moulded, and deeper.

Buttresses increased in importance as the larger windows reduced the wall areas and, with the introduction of flying buttresses, they were in consequence much wider. The richness of the interiors was reflected in the ornamental niches and crocketed gables on the buttresses. The angle buttress was introduced during this period (Fig. 79C).

Mouldings were similar to those in the previous

period, but with less deep sinkings, producing an undulating profile.

The ball flower was the typical ornament (Fig. 80c). Foliage was naturalistic, and heraldry and symbolism came into use. Diapered

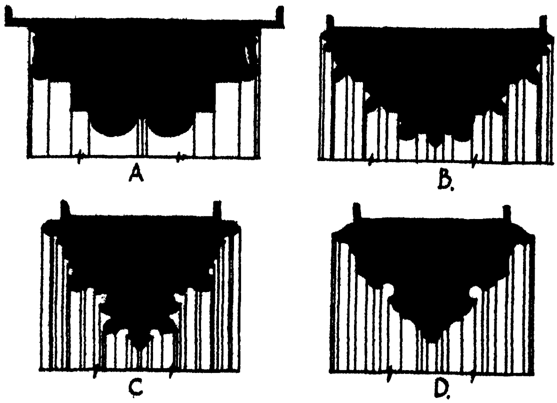


FIG. 82. ARCH MOULDINGS

A = Norman
B = Early English
C = Decorated
D = Perpendicular

patterns were carved on wall surfaces as at Westminster, and wall arcading was developed. Sculpture was at its best during this period.

Examples of the style are to be seen at Westminster (Chapter House), Lincoln (the Angel Choir), Salisbury (Chapter House), York (Choir and Chapter House).

Perpendicular Period. This name, by which the late Gothic style is known, is also somewhat inappropriate, for most Gothic work

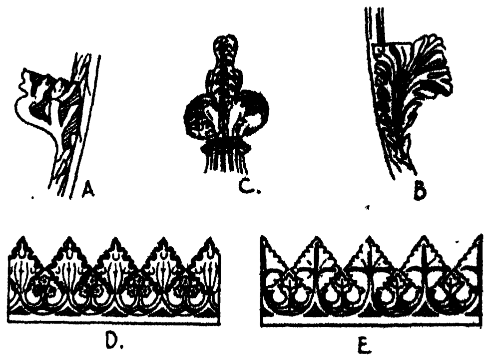


FIG. 84

A and *B* = Crockets
C = Poppyhead Finial
D and *E* = Crestings

is strong with vertical lines. It is sometimes better named *rectilinear*. Windows were often of great size, one of the finest being the eastern window at Gloucester, which is 72 ft. high and 38 ft. wide. They were subdivided by vertical

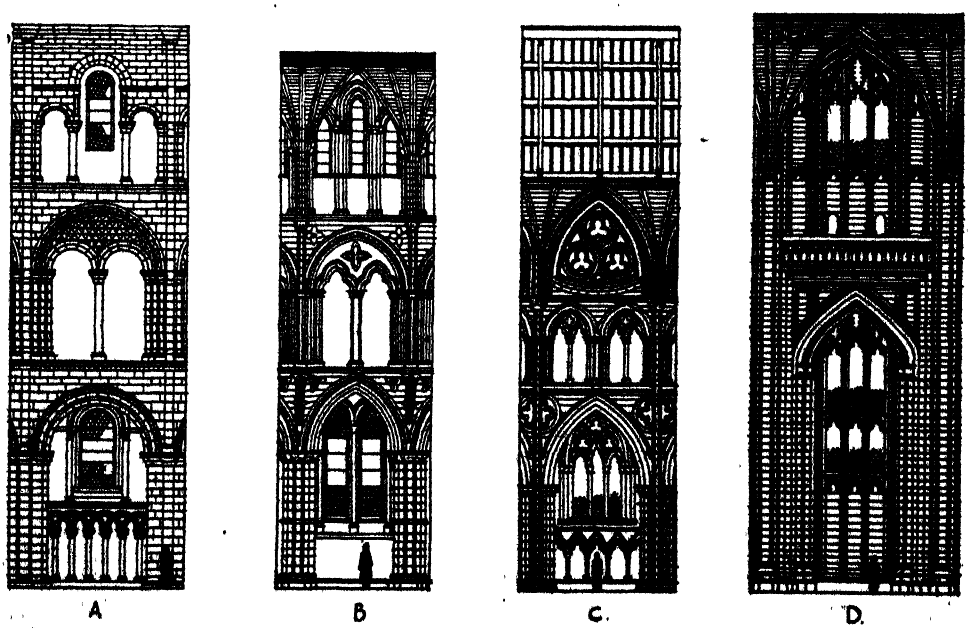


FIG. 83. TYPICAL BAYS

A = Peterborough (*Norman*)
B = Ely (*Early English*)
C = Lichfield (*Decorated*)
D = Winchester (*Perpendicular, remodelled on Norman work*)

bars, or *mullions*, which sometimes extended from the sill to the arch, strengthened at intervals by transoms. The upper parts were foliated (Fig. 76J). Arches were flatter than previously, and ultimately became four-centred, known as *depressed*, or Tudor, arches (Fig. 76B).

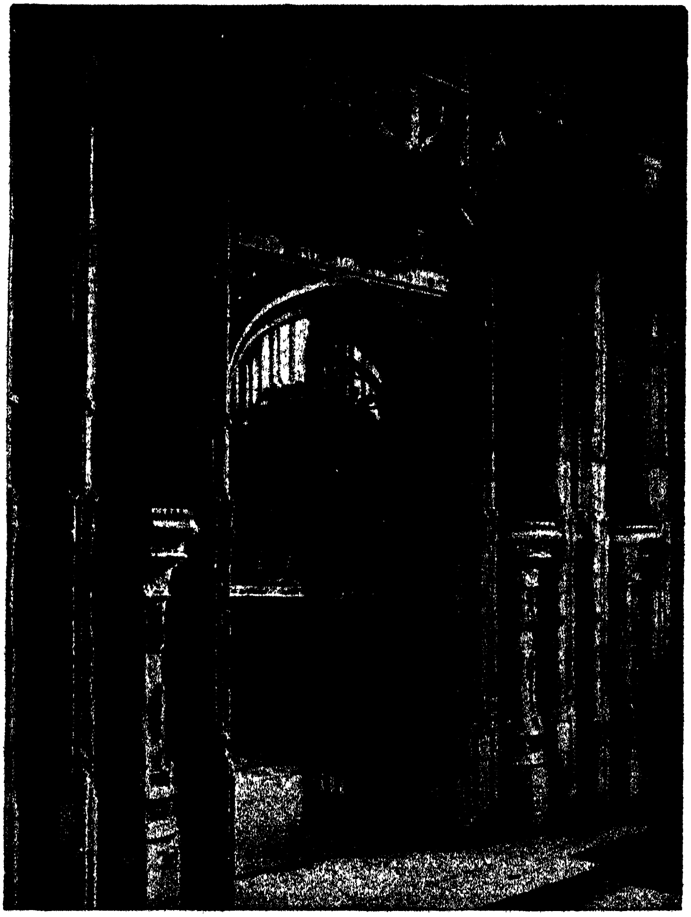


FIG. 85. ELY CATHEDRAL, ENTRANCE TO BISHOP WEST'S CHANTRY
(Late Perpendicular)

Another form, the *ogee*, was an arch of double curvature (Fig. 76C), but was chiefly used for small features, such as niches. Doorways were usually flatter, frequently having a rectangular hood, or drip, mould over with carved spandrils (Fig. 76B).

Columns consisted of circular shafts connected by hollows, with small capitals to the shafts, and the hollows conforming with the moulding of the arch and being continuous with it. Capitals, when moulded, were less strong in outline ; carved foliage again tended to become stiff and conventional. They were sometimes polygonal on plan, as were the bases to piers.

Ornament was chiefly conventional, the Tudor rose and the fleur-de-lis being frequently used. Wall surfaces were panelled wherever possible, repeating the tracery used in window openings. Mouldings usually developed along splayed surfaces, with very slight sinkings.

Examples: Henry VII's Chapel, Westminster, Bath Abbey, the West fronts of Beverley, Gloucester, and Winchester, and the remodelled Norman nave at the latter, St. George's Chapel, Windsor, and King's College Chapel, Cambridge.

GENERAL DETAILS

NAVE DESIGN. In early buildings, the three divisions *Nave arcade*, *Triforium*, and *Clerestory* were of more or less equal height, but later, the triforium became of less importance and was sometimes linked up with the clerestory. In late examples, the triforium is almost entirely suppressed, as at Winchester, where it consists only of a small gallery expressed by a range of panelling. Typical bays are illustrated in Fig. 83.

SPIRES. The towers of cathedrals and churches were often crowned with a tall spire, usually octagonal. The earliest form of importance was the broach spire which rose direct from the tower, and is characteristic of the thirteenth century. Later a parapet and small angle pinnacles were introduced. There are fine examples at Salisbury, Lichfield, Chichester, Norwich, and many of the parish churches throughout England.

PINNACLE. A small turret often placed on top of buttresses, as in Figs. 69 and 70 ; often decorated with crockets, it has structural significance in adding to the weight of the buttress, which resists the thrust of the flying buttress.

CROCKET. Small carved projections decorating the angles of spires and pinnacles, and on the hood moulds over doors and canopies (Fig. 84 A and B).

FINIAL. The crowning feature as to a pinnacle or bench end. The poppy-head was a much used type (Fig. 84c).

GARGOYLE. A projecting outlet from the gutter through which rain-water was discharged; often grotesquely carved.

GALILEE PORCH. A porch built near the west end of many abbey cathedrals, intended for the use of penitents

PISCINA. A niche in the wall usually near the altar, from which a small duct carried away water used for washing vessels after the services of the Sacrament.

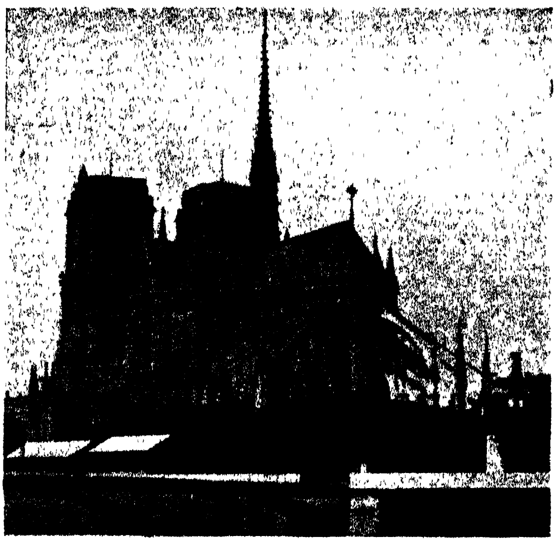


FIG. 86. NOTRE-DAME, PARIS, FROM THE SOUTH-EAST

REREDOS. The ornamental screen at the back of the altar.

ROOD-LOFT. A small gallery across the front of the chancel supporting the crucifix, or rood; the lower part served as a screen.

In some cases there is no screen, and a *rood-beam* supports the crucifix.

TIMBER ROOFS. Space will not permit an illustrated description of the development of the open timber roof. Many interesting types were evolved in development from the early Tie-beam roof to the complex and beautiful Hammer-beam roofs such as those at Westminster Hall, Middle Temple Hall, and Hampton Court.

CONTINENTAL GOTHIC

In order to trace the evolution of Gothic architecture by reference to actual examples, or readily obtainable illustrations of the style in our own country, English work has been considered first, but it must be pointed out that it is generally and rightly accepted that the French were foremost in the development of Romanesque and Gothic architecture which spread throughout Europe.

France. Structural considerations resulted in many similarities to work in England, but apart from the variations in detail which cannot be described here, French cathedrals differ from those in England both in location and plan. They were not built as parts of monastic establishments in secluded and peaceful surroundings, but were usually erected in the busy parts of the cities, entering very largely into the lives of the people who contributed towards their cost. Numerous side chapels were provided for the worship of saints and saying of masses, these chapels being sometimes arranged around the east end forming the *chevêt* (see Fig. 87). Transepts had but slight projection, and the cathedrals were generally simpler in massing, taller, but not so long, although in some cases more imposing than those in England.

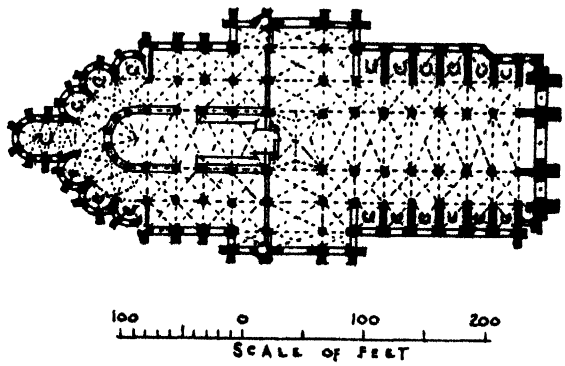


FIG. 87. AMIENS CATHEDRAL (PLAN)

The western towers are characteristic features, as at Notre-Dame; the central tower, or spire, is not common, although a wooden *flèche* was frequently provided over the crossing.

Over 100 cathedrals were built, chiefly during the first half of the thirteenth century. One of the finest is that of Notre-Dame, Paris (1163–1214). The west front is exceedingly fine, having two stately towers, three deeply recessed and richly ornamented portals, and a fine circular wheel-window in the gable—all of which are characteristic features. Among the many other beautiful churches are Amiens Cathedral (1220–1288), with its vast interior 140 ft. high to the

FIG. 88. AMIENS CATHEDRAL
The Interior looking East

FIG. 89. ANTWERP CATHEDRAL

FIG. 90. MILAN CATHEDRAL

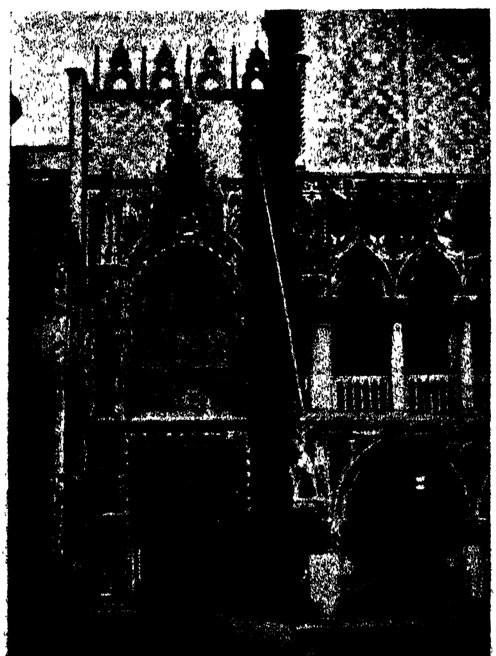


FIG. 91. THE DOGE'S PALACE, VENICE
The Entrance

vaulting (Fig. 88) and Chartres Cathedral, noted for its magnificent stained glass windows.

Belgium. Antwerp Cathedral (Fig. 89) is probably the finest church in Belgium, and is remarkable for its plan, which has three aisles on each side of the nave, giving a total width of 160 ft. The west front, which was built during the last half of the fifteenth century, is floridly decorated in the manner of the time, and a lofty tower is characteristic both of the cathedrals and the town halls of Belgium.

Italy. Apart from the strong classic tradition which permeated the architecture of Italy, the brilliant climate of the country rendered the steep roofs and large windows of the Gothic style unsuitable. While, therefore, the influence of the style is to be seen in many of the buildings, local traditions and materials produced results different from those in Northern Europe. The use of brickwork, terra-cotta, and marble and mosaic facings resulted in the general reliance upon colour rather than light and shade for effect.

The cathedral at Milan (1385–1418) (Fig. 90) is one of the exceptions, being built entirely of white marble. It is the second largest mediaeval church, and is excessively rich, both externally and internally. Purists are inclined to condemn the painted vault, but it is very frankly *surface* decoration, and contributes largely to the effect of one of the most wonderful interiors existing.

In Venice, important as a rich trading centre, are many fine examples of domestic architecture in the Gothic style. The Doge's Palace, Fig. 91, built during the first half of the fifteenth century, is probably the finest example of its kind.

Germany. Romanesque architecture was developed to a greater extent and for a longer period than elsewhere, and the Gothic style was not adopted from France until the thirteenth century. The cathedral at Cologne is the finest example, being over 150 ft. high to the vaulting. The twin spires on the western front are 512 ft. high.

Spain. The Gothic style was developed on French lines, but is peculiar for the wide spans used. In Seville Cathedral (1401–1520), which is the largest mediaeval church in the world, the aisles are equal in size to the nave of Westminster Abbey, while the nave is about 50 ft. wide and 130 ft. high.

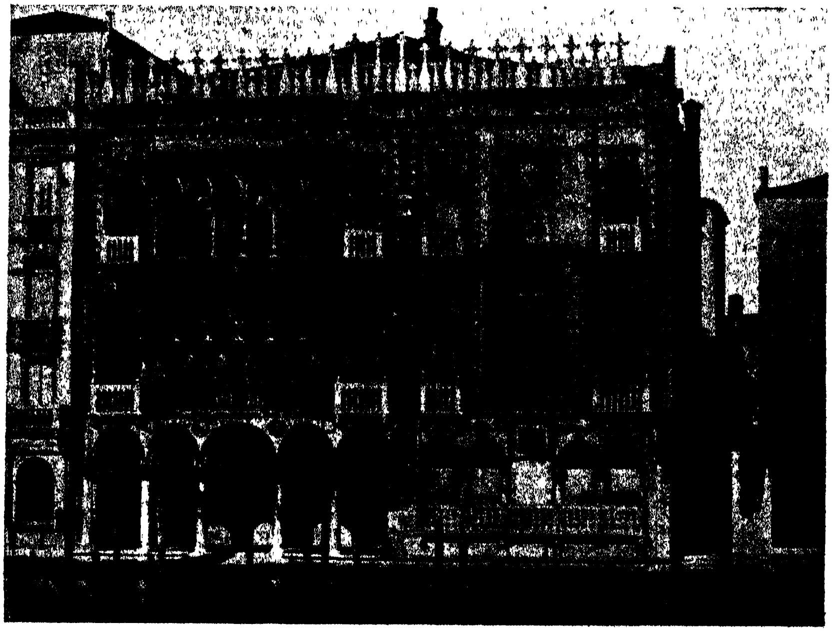


FIG. 92. CA D'ORO, VENICE

SECULAR ARCHITECTURE

A history of mediaeval architecture is concerned almost entirely with buildings of a religious character. Relatively few of those which formed part of the civic or private life of the people remain, and those frequently because of the substantial manner in which they were built, with security in mind rather than beauty. In England, few buildings remain which were erected prior to the fifteenth century, and even of that century good examples are scarce.

Chapter VI—RENAISSANCE ARCHITECTURE

THE Renaissance, or rebirth, is the very appropriate name given to that period which marked the emergence of Western civilization from the ignorance and narrow ecclesiasticism of the Middle Ages. Many factors contributed towards the movement, which may be said to have begun in Italy about 1400, and to have taken firm hold in France and England some two hundred years later. The discovery of America and of new lands in the Far East, of art and literature of Greek and Latin antiquity, reaction against the authority of the Church, the invention of printing, which made possible the spread of knowledge—these, and many local causes, led people, in a spirit of inquiry, out of the dark paths of the Middle Ages.

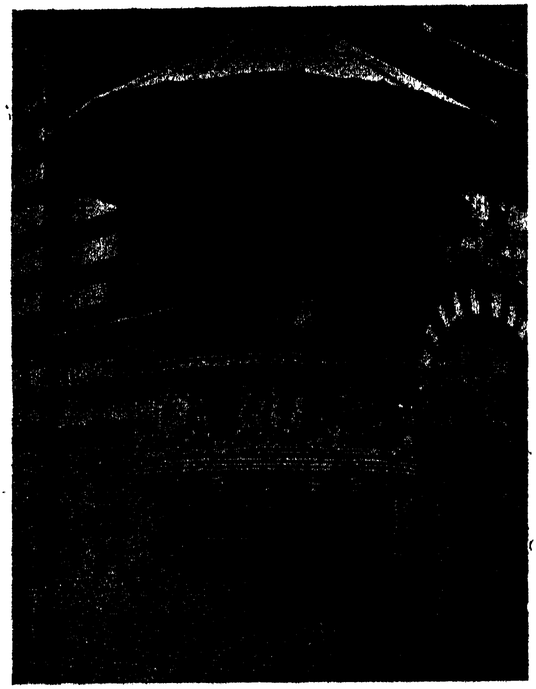


FIG. 93. THE OUTSIDE PULPIT, PRATO, TUSCANY
By Donatello

With the advent of forms of central government and the subduing of feudalism, almost constant warfare gave way to the pursuits of peace. As mediaeval architecture had been largely controlled by the Church, so that which followed was chiefly devoted to the domestic requirements of the people. Gothic architecture had lent itself very readily to domestic buildings, as examples in Venice and in France show, but with the Renaissance movement, architecture underwent great changes, resulting from a revival of classic art, first in Italy, and then to spread over the whole of Western Europe.

ITALIAN

The Renaissance found its earliest manifestation in Italy. Dante and other writers had popularized the newly discovered classic literature, and when Constantinople fell to the Turks in 1453, Greek scholars fled westward, taking with them manuscripts and sculptures which revealed in almost complete form the thought and art which had constituted the Greek civilization of the pre-Christian era, and the cities of Italy became centres of education. It was natural, then, that there should arise a new interest in classic architecture, although the classic traditions had ever been too strong to allow the Gothic style to take root and become a national style as it had in England and France.

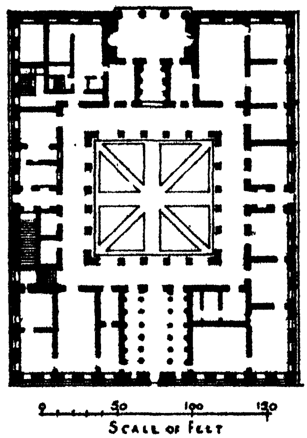


FIG. 94. FARNESE PALACE, ROME
Ground Floor Plan

Italy of the fourteenth century, it should be

appreciated, was not the united nation of the present day, but consisted of a number of smaller states, of which the Republic of Florence was not only the most powerful but the most advanced in literature and the fine arts; other states were the Kingdom of Naples, the Duchy of Milan, the Republic of Venice, and the Papacy, which, on the return of the Popes from Avignon to Rome in 1376, restored Rome to its former place as one of the foremost cities of Italy.

The most important centres in which the Renaissance developed were Florence, Rome, and Venice. Works in these cities and surrounding districts possess certain local characteristics, due not only to local traditions, but also to the individuality of the designers, in which respect Renaissance architecture differs considerably from that which preceded it. Although history records the names of a few men who were the master minds in the erection of some of the great mediaeval buildings, it appears that they were usually master craftsmen, having authority over their fellow workers by virtue of superior skill in their craft. In the Renaissance, however, the individuality of the designer is of great importance; he followed not one craft but many, being trained in a *botteghe*, or workshop, in which the master and his apprentices carried out the work of architect, sculptor, painter, or worker in metal as opportunity offered. The great artists of the Early Renaissance—Brunelleschi, Ghiberti, della Robbia, Cellini, and others—all had this training, though usually achieving fame in only one of the many arts which they practised. These designers often showed great skill in the design and execution of the decorative accessories of architecture, such as doorways, fonts, etc. The pulpit in Fig. 93 is an excellent example.

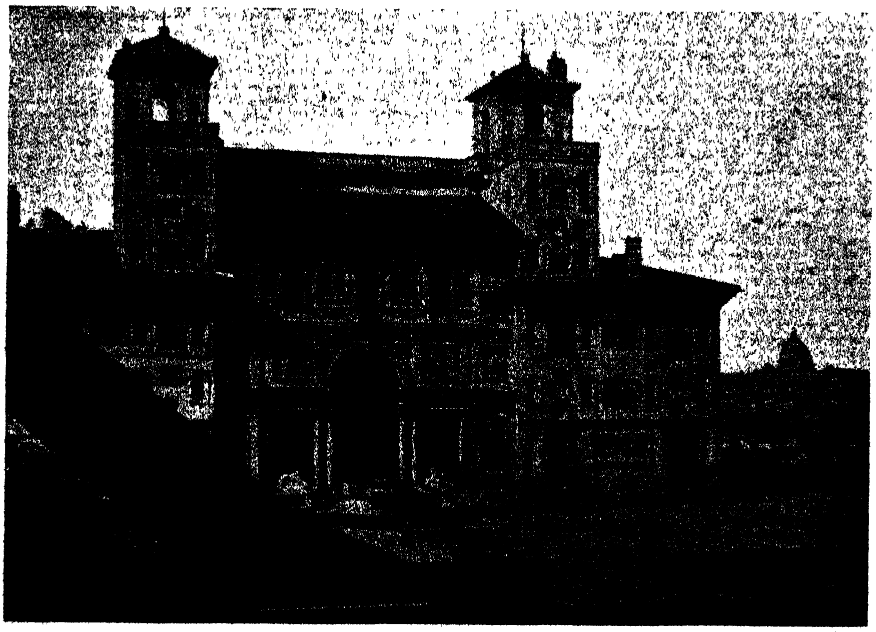


FIG. 95. VILLA MEDICI, ROME, 1540

Residences. With the advance of civilization much authority and power passed from the Church to the merchants and their guilds, and the demand for civil and domestic buildings increased. The wealthy nobles and merchants—and in Rome, the Popes, who were temporal princes—were the great patrons of the new art, and many fine palaces were erected for them.

In plan, these palaces invariably consisted of a number of apartments ranged around a courtyard, or *cortile* (Fig. 94), on each side of which was an arcaded covered way with sometimes a gallery over.

The Roman Orders were the chief features

employed in the design of the façades, but they were by no means used in a mere imitative manner; many interesting and new compositions were evolved, and the decoration of wall

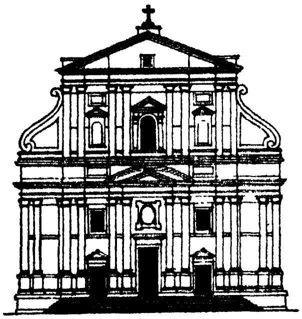


FIG. 96. CHURCH OF IL JESU, ROME
The Entrance Façade
Architect, Vignola

surfaces by means of rustication contributed very largely to the general effect.

They were of two general types: those with pilasters or columns, and those without (Fig. 100 A and B); the latter are often referred to as *astylar*, and are typical of the early examples in Florence. Treatments of the first type were of great variety, having an Order to each story; a plain or rusticated ground floor with Orders over; and, in later examples, an Order incorporating two stories.

Many of the interiors were planned on noble lines, recalling the grandeur of the classic examples which inspired their designers.

Country villas naturally permitted greater freedom in design, and they were often surrounded by fine terraces and gardens. The Villa Medici (Fig. 95) is an excellent example, although more ornate than the majority.

Churches. Many of the earlier churches were similar in plan to the basilican churches already described, but later the provision of a fine dome was one of the controlling factors in their design. Many types were evolved, usually developing out of a square or octagon into a Greek cross, and at times having an extended nave.

Externally, the dome is frequently a prominent feature, and the Orders were employed in the façades. In many cases, the entrance façades show a single Order to the aisles, with another added to the nave, Fig. 96; but later many façades were designed without close reference to the section, as in Fig. 97.

It is not possible to give details of the fine plans and façades of these buildings; readers are referred to the many extensive works dealing with the history of the Renaissance, and in particular to the monumental work by Letarouilly, a collection of plates illustrating many of the finest buildings of Rome.

Florence. It was in Florence, under the patronage of the famous Medici family, that the Renaissance art was first established. Many smaller works had been executed, but the first outstanding personality was Brunelleschi (1377–1446), a Florentine, who had studied the remains of the works of ancient Rome while working there as a goldsmith. His great work was the dome of Florence Cathedral (1420–1434), a vast structure having a span of 138 ft. 6 in., which covers the octagonal crossing of a building commenced at the end of the thirteenth century. Many interesting and romantic stories are told of the carrying out of this great work, which it is said was erected without the use of centering. Brunelleschi was also responsible for a number of other churches, one of the finest being the Pazzi Chapel, Florence (Fig. 99).

The Palazzo Riccardi (Fig. 100A) with its heavily rusticated walls, bold detail, and massive

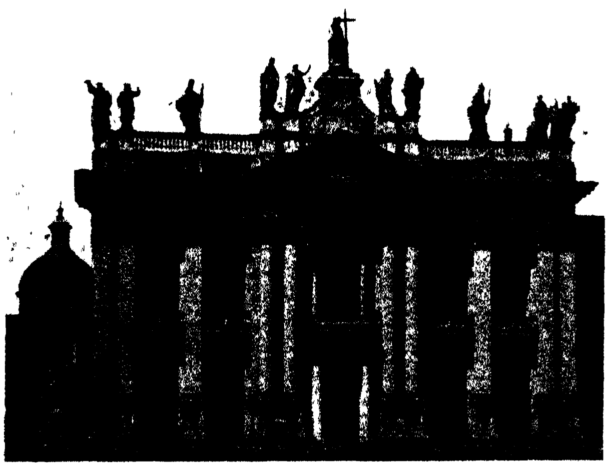


FIG. 97. S. GIOVANNI IN LATERANO, ROME

cornice, is typical of contemporary palaces in Florence.

Another important architect of the Florentine school was Alberti (1404–1472), who designed the Palazzo Ruccellai, Fig. 100B, probably the first Renaissance building in which the Orders were employed in this manner.

Rome. Not only was Rome the religious

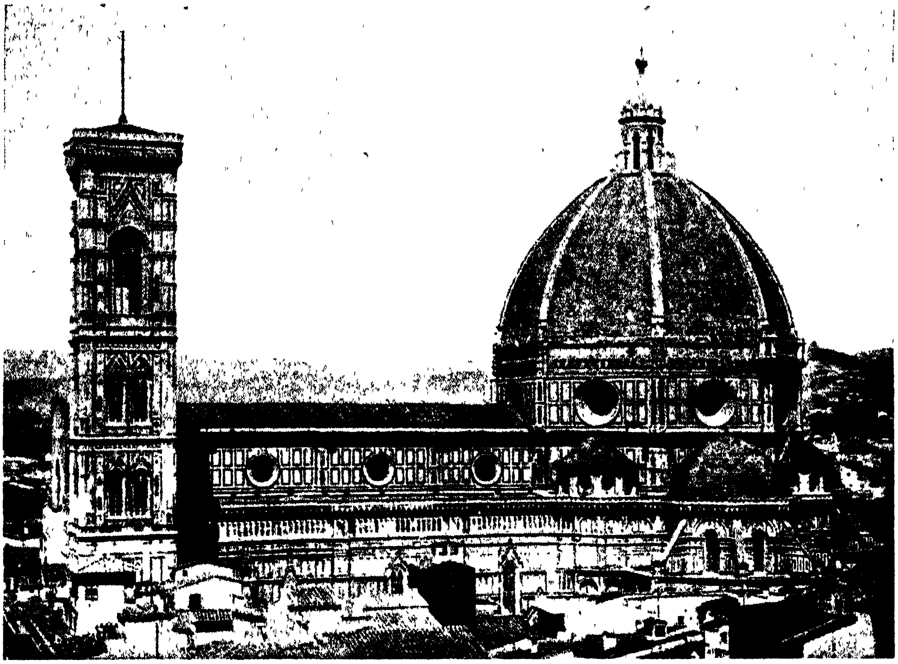


FIG. 98. FLORENCE CATHEDRAL

FIG. 99. THE PAZZI CHAPEL, FLORENCE
The Portico

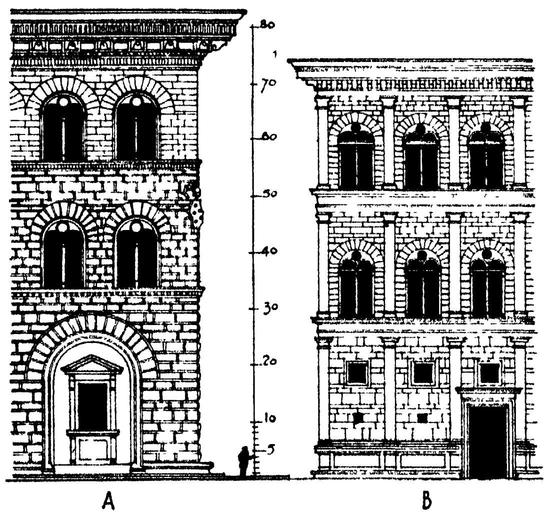


FIG. 100
A = Palazzo Riccardi, Florence
B = Palazzo Ruccellai, Florence

centre, but it was important as the one-time capital of a great empire, whose ruins were so important as models for the new style. During the fifteenth century, under the rule of the Borgias, there came an era of prosperity, during which many fine palaces and churches were erected, and existing ones decorated by the great painters of the time, among whom were Raphael and Michael Angelo. As Rome flourished, many Florentine artists were attracted to that city by the wealthy patrons of the fine arts.

The first architect of note was Bramante (1444–1514), a Florentine, who was responsible for many buildings; he also prepared a number

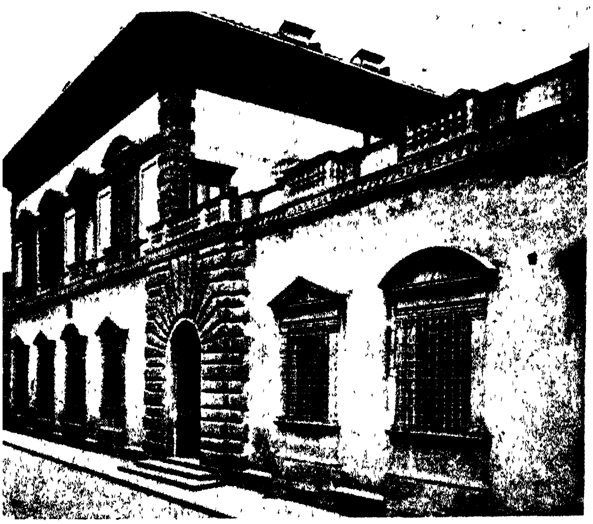


FIG. 101. PALAZZO PANDOLFINI, FLORENCE

of drawings for St. Peter's, Rome, which, however, were not carried out. Among his many pupils and followers were—

Peruzzi, who designed a number of buildings in Rome.

Sangallo the Younger, who was responsible for one of the finest buildings of the period, the Farnese Palace, Rome (Fig. 94).

Raphael, who did a little work on St. Peter's, and designed the Pandolfini Palace, Florence (Fig. 101), but this was not built until after his death.

Vignola (1507–1573) was one of the great men of the Renaissance. He not only worked on St. Peter's and carried out other works in Italy, but wrote a well-known treatise on *The Five Orders of Architecture.*

Michael Angelo (1474–1564), also a Florentine, was famous as a painter and sculptor who later turned his attention to architecture, carrying out the Capitol Buildings, Rome, and a great amount of work on St. Peter's, including the dome.

The most important building erected was St. Peter's. It is only possible to give a brief

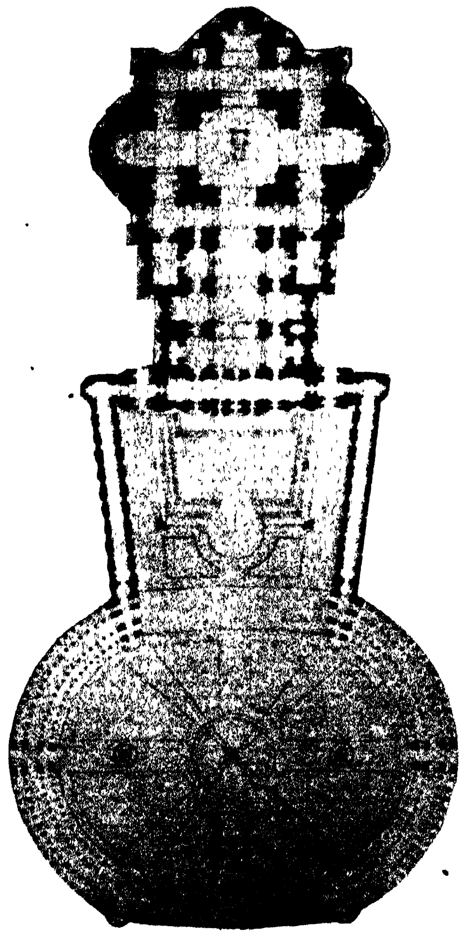


FIG. 102. ST. PETER'S, ROME

history of this building, in the erection of which many architects were concerned. Bramante prepared the original scheme, and the foundation stone was laid in 1506. Sangallo and others were subsequently entrusted with the work, and proposed many alterations to the original Greek cross plan-form of Bramante.

In 1546 Michael Angelo was appointed; he returned to the plan-form proposed by Bramante, although simplifying it; the great dome was designed and its construction commenced.

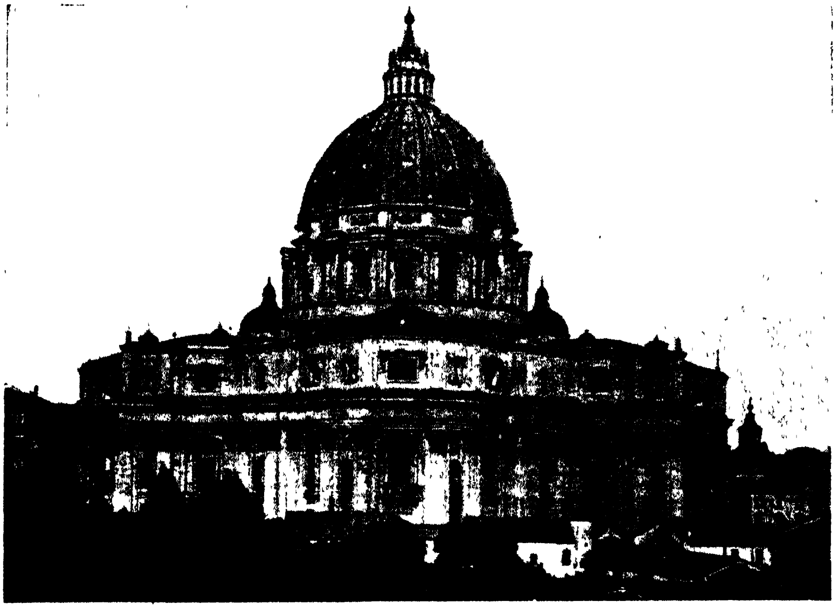


FIG. 103. ST. PETER'S, ROME, FROM THE WEST

(*Note.* St Peter's and many of the early churches in Rome were not orientated in the manner usual with Christian churches)

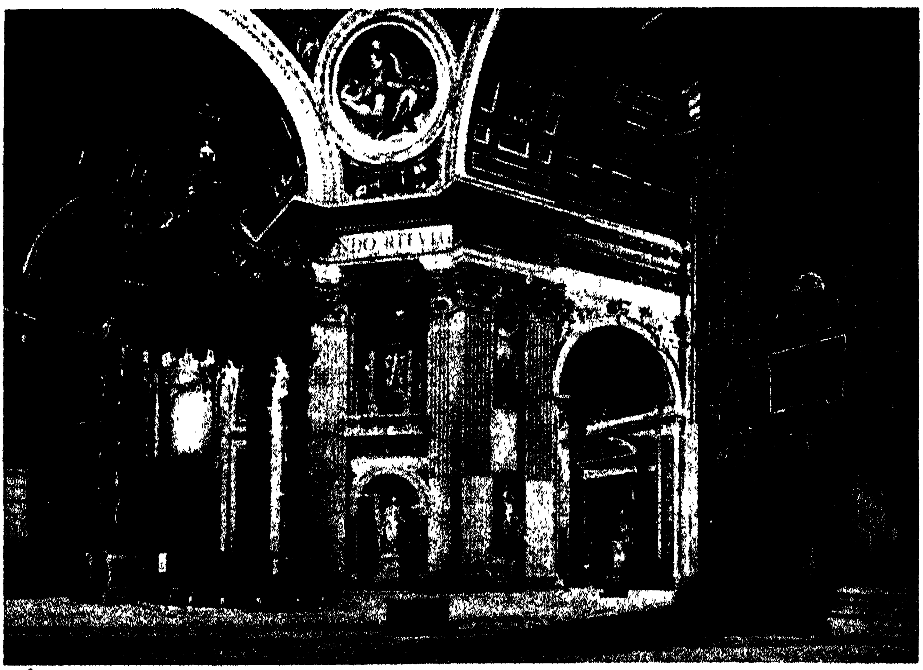


FIG. 104. ST. PETER'S, ROME

Interior showing the piers under the dome

On his death, in 1564, Vignola was entrusted with the building, but did very little except to add the cupolas.

In 1588 Giacomo della Porta and Domenico Fontana commenced the construction of the dome, varying somewhat from the models and

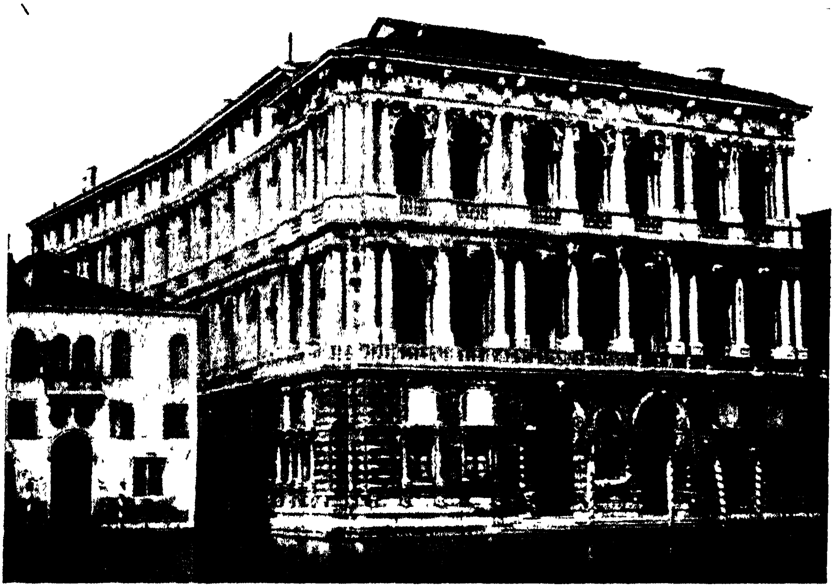


FIG. 105. PALAZZO PESARO, VENICE

drawings which Michael Angelo had left; the work was finished in the incredibly short time of twenty-two months. Unfortunately, the nave

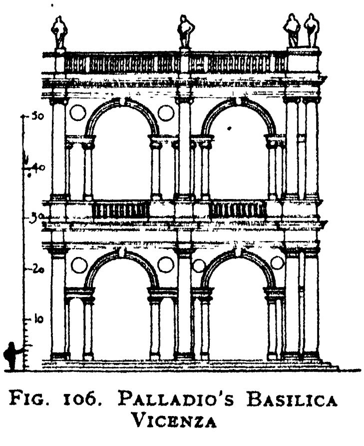


FIG. 106. PALLADIO'S BASILICA VICENZA

was lengthened in 1605, and the present gigantic façade begun by which the view of the dome is cut off, except from a distance. The colonnades enclosing the forecourt were erected later by Bernini, who also designed the baldachino under the dome.

The following are the principal dimensions: dome, 137 ft. 6 in. in diameter; nave, 80 ft. wide; the lantern is about 88 ft. high, the top of which is just over 400 ft. above the ground. The Order employed on the façades is 108 ft. high.

Venice, still important as a trading centre with the East, flourished during the early and middle Renaissance times, but with the coming of Turkish rule in Constantinople, and the discovery of sea routes between Western Europe and India by way of the Cape, her supremacy began to wane, but not until the Renaissance had produced a great number of beautiful buildings. Gothic architecture had taken a firmer hold than in the south, and many fine palaces had been built in that style. It followed, then, that there should be a period of transition, in which Gothic and Renaissance details are intermingled in a graceful and delicate manner.

Sansovino (1479–1570) was one of the best known architects, who designed the Library of St. Mark's, Venice, and many palaces.

The Palazzo Pesaro (Fig. 105) is a later example, erected during the latter half of the seventeenth century by Longhena, who also designed the beautiful church of S. Maria della Salute.

Vicenza, famous as the birthplace and the scene of many of the works of Palladio (1518–1580), contains the celebrated Basilica, of which he designed the arcaded façade (Fig. 106). The peculiar spacing was necessary in order to conform to the mediaeval building to which it is attached; the feature which is repeated in each bay is known as the *Palladian motif.* Palladio built a number of churches in Venice, and his writings and drawings of Roman antiquities, in which he advocated the simplicity which he practised, were widely read in this country, where they exercised great influence.

THE ROCOCO, OR BAROQUE, PHASE. It was inevitable that there should be reactions against the severity and simplicity of the late sixteenth century, and during the period which followed great freedom was exercised in the handling of features of classic origin; the work is frequently referred to by the foregoing names. Such features as voluted and broken pediments, projecting columns with the entablature breaking forward over them, twisted columns, and sometimes excessive ornament are typical, and sometimes worthy of the description " debased " or " decadent," but it must not be overlooked that many fine works, such as Bernini's colonnade in front of St. Peter's, Rome, were carried out during the late Renaissance.

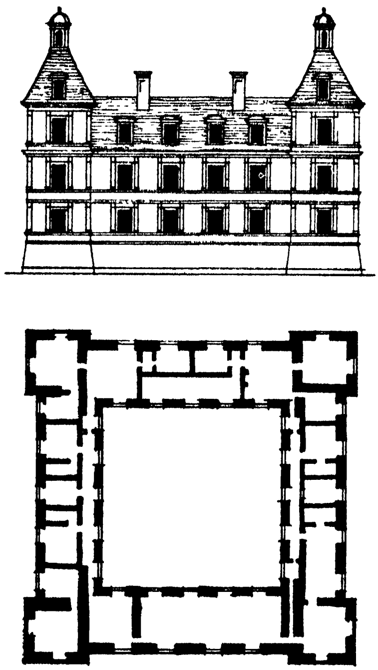


FIG. 107. CHÂTEAU OF ANCY-LE-FRANC

FRENCH

French architecture prior to the Renaissance was essentially a national style. France had been rich in monuments of Roman greatness, particularly in Provence, but northern invaders who came after the Romans had not been capable of carrying on the traditions. In due course the Romanesque and then the Gothic styles had been developed; indeed, the latter had reached a state of perfection when no further progress seemed possible, and architecture tended to lose itself in " ingenuities of design and dexterities of construction " (*Ward*). The arts underwent a decline during the Hundred Years War, but there followed a great period of prosperity, and with it an outburst of architectural activity. Many smaller works of art and books had found their way into France during the fifteenth century, but France knew little of the great movement which was going on in Italy until the armies of Charles VIII invaded Tuscany in 1494.

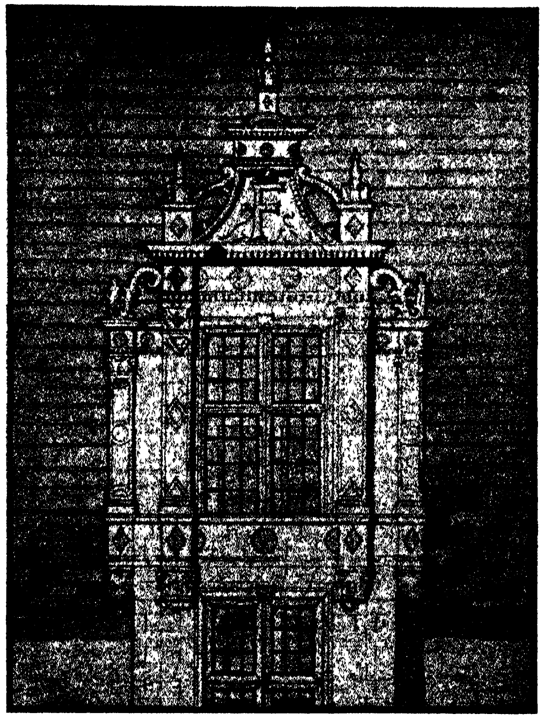


FIG. 108. THE CHÂTEAU OF CHAMBORD
A dormer window

So greatly was he impressed, that the king not only sent large quantities of tapestries, pictures, and marbles to France, but took with him a number of artists who were to work on a great château which was contemplated at Amboise.

The development of the Renaissance architecture in France was continuous, and subdivision is difficult. Some phases are named after the monarch during whose reign they were developed, particularly those of Louis XV and Louis XVI, and the Empire, but it will be well in this brief outline to refer to the *early, classic* or *mature*, and *late* or *Rococo* periods, covering the sixteenth, seventeenth, and eighteenth centuries, respectively.

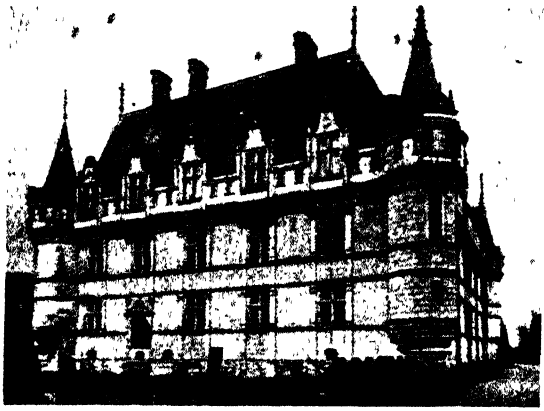


FIG 109. THE CHÂTEAU OF AZAY-LE-RIDEAU (*c* 1520)

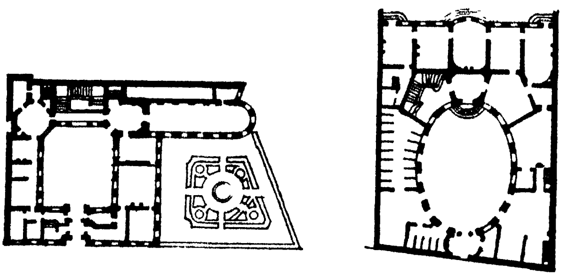


FIG. 110
Left = Hôtel Lambert, Paris
Right = Hôtel d'Amelot, Paris

Early Renaissance. Under François I many country houses, or châteaux, were built, particularly in the Loire district, through which the influence of the Italian colony at Amboise had spread. Despite the more settled conditions of the country, these houses retained many defensive features, such as moats, drawbridges, and towers; the latter, as angle pavilions, are characteristic of French architecture. In plan, the various apartments were usually arranged around a courtyard, sometimes treated in a manner reminiscent of the "cortile" of the Italian palace (Fig. 107). Roofs were steeply pitched and decorated with metal and pottery enrichments, such as crestings, while a profusion of richly decorated chimney-stacks and dormer windows produced very picturesque buildings.

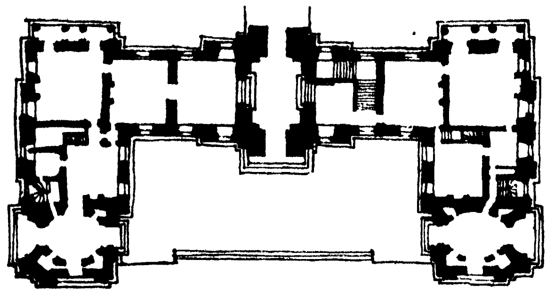


FIG. 111. CHÂTEAU OF MAISONS, NEAR PARIS

The Château of Chambord (1526–44) was the most important, but apart from its symmetrical plan it does not show any substantial appreciation of the classic movement. The most striking feature is the roof, with its multitude of chimney-stacks, dormers, and turrets.

The château at Azay-le-Rideau (Fig. 109) is one of the most attractive of the Loire châteaux, and is typical of the best work of this very fascinating phase of French architecture.

The Hôtel de Ville, Paris, was begun in 1532 by an Italian "Boccador"; it was burnt down in the nineteenth century, but its original design was substantially reproduced when it was rebuilt.

Among the French architects of this period, Pierre Lescot (1515–78) is one of the best known. He was associated in many works with Jean Goujon (1510–72), a sculptor whose skill in the design of sculpture related to architecture has seldom been equalled. In 1546 they began the building of the Louvre, which was to replace an old fortress deemed unfit for the seat of the Court, which was settling in Paris. Their original design was abandoned for a larger scheme after one wing had been built, and subsequent additions were made by various architects during the sixteenth and seventeenth centuries, and later, during the nineteenth century. Fig. 112 illustrates work of this latter

period. in which the character and detail of the earlier work was substantially reproduced.

Classic, or Mature, Period. The Renaissance now had a firm hold, and was better understood by French architects.

With the Court and administrative authorities settled in Paris, many town houses, or *hôtels*, were erected. These were usually planned with a central courtyard, and the living apartments removed from the street frontage, towards which was usually a plain wall with one common entrance for residents and coaches (Fig. 110).

Many châteaux were built, but in these the tendency was to eliminate the courtyard and to provide for finer views across the sometimes beautiful gardens. The moat was frequently retained in the form of a sunken garden.

There were two general types of architectural treatment of elevations. In those of stone, the Orders were frequently employed, with an Order, usually pilasters, to each story. The Château of Maisons, illustrated in the plate opposite page 1207, is an excellent example of this type. In many other buildings brickwork was used, and the introduction of stone rustications, both at angles and around and between window openings, produced a sometimes interesting effect (Fig. 113). These rustications are known as *chaines*.

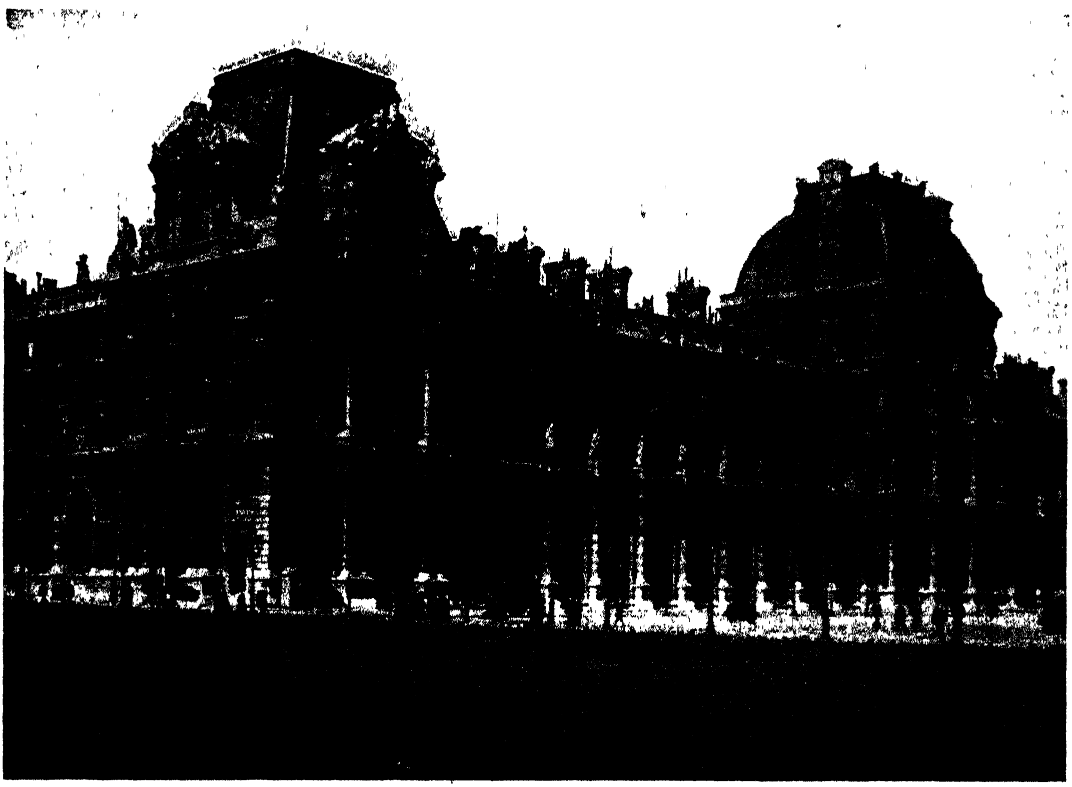


FIG. 112 THE LOUVRE, PARIS

Roofs remained steep, and in many cases the various blocks of building were roofed separately. The mansard roof was popularized by F. Mansard, but was not invented by him, as is sometimes supposed. Curved roofs were employed, particularly in the form of a square dome over pavilions, a feature which is characteristically French.

A number of churches were erected, based either on the basilican or cruciform plan-form, some having very fine domes.

The following were the outstanding architects of the period, and their most important works—

De Brosse (1562–1626), who designed the Luxembourg Palace, Paris, and a number of châteaux.

Lemercier (1585–1654), for some time architect

to the Louvre and also of the church of the Sorbonne.

F. Mansard (1598–1666), who was responsible for a large number of town and country houses, the best known being the Château of Maisons. He also designed the church of Val de Grace.

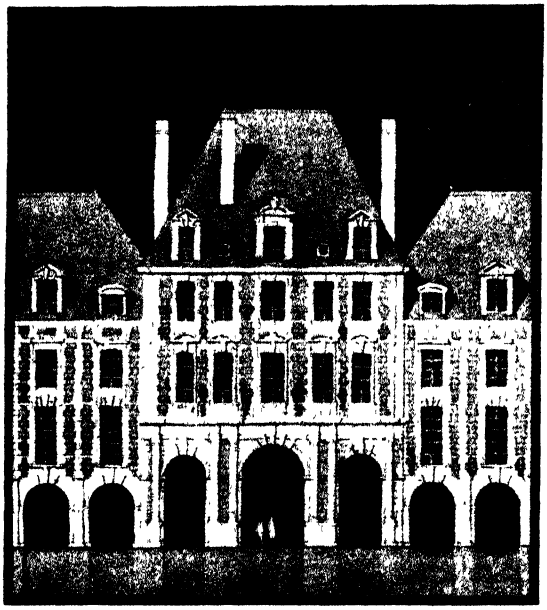


FIG. 113. PLACE DES VOSGES, PARIS (c 1604)

Le Vau (1612–70), successor to Lemercier as architect to the Louvre in 1654; was architect of the College Mazarin, now known as the L'Institut. In 1661 he was commissioned to enlarge a château at Versailles, believed to have been designed by De Brosse; this building, now famous as the Palace of Versailles, was added to later by J. H. Mansard and J. A. Gabriel.

The outstanding figure of the late seventeenth century was J. H. Mansard (1643–1708) who added wings to Versailles and the chapel. This great building is typical in detail of the best work of the period, but can hardly be considered a great achievement, except in size. It is of one height throughout, and there is no visible roof except for that of the chapel, which is but barely related to the main building, although very fine in itself. Among his many other works are the Place Vendôme and the Place des Victoires in Paris, and the second church of the Invalides, which is probably his finest building (Fig. 114).

Late Renaissance. This period covers the

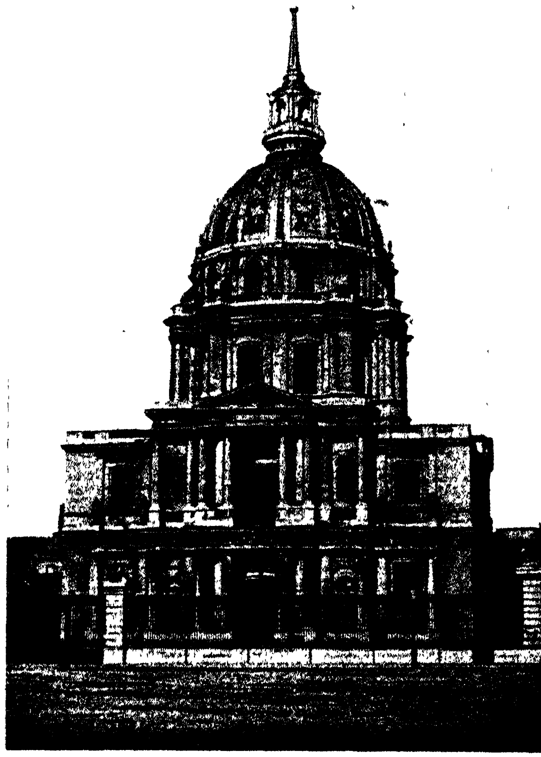


FIG. 114. LES INVALIDES, PARIS

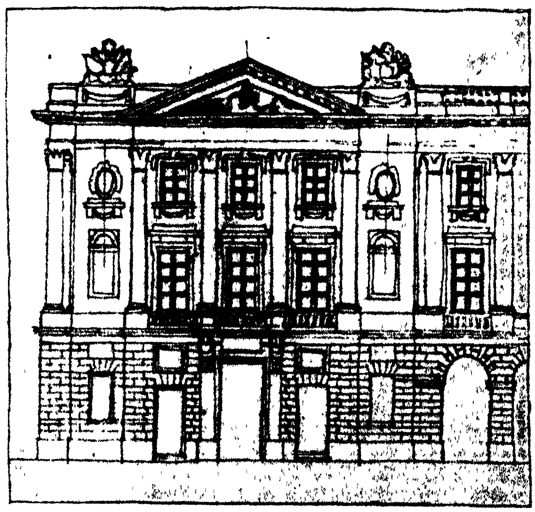


FIG. 115. END PAVILION OF ONE OF THE BUILDINGS IN PLACE DE LA CONCORDE, PARIS, BY GABRIEL

reigns of Louis XV and Louis XVI, both of whom have given their names to styles of interior decoration.

The outstanding personalities were J. A. Gabriel (1710–82) and J. G. Soufflot (1709–80), through whose influence there was a return to simplicity, and the naturalistic freedom in ornament gave way to conventional forms typical of classical traditions. In the use of the Orders on more important and larger buildings, there were great changes. Instead of an Order to each story, characteristic work shows an Order, embracing the first and second stories, placed upon a rusticated ground floor (Fig. 115).

The most important works were as follow—

J. A. Gabriel's most important work was the Place de la Concorde (originally known as the Place Louis Quinze), with its twin buildings. He secured this commission as the result of a competition in which many architects took part, but his design was to some extent adjusted to incorporate the best features contained in some of the other designs submitted. At Versailles he added pavilions on either side of the entrance court, and at some little distance from the Palace built the Petit Trianon (1762–68), a private residence for Louis XV (Fig. 116). Although not very large—79 ft. by 73 ft.—it is one of the finest buildings of the period, and contains many excellent interiors. Other important buildings were the École Militaire, typical of the best work of the period, and the palace at Compiègne.

J. G. Soufflot started the Pantheon in 1757. It was one of the most important buildings erected during the latter half of the seventeenth century. It is a Greek cross on plan, having domes over the arms and the crossing, but the latter is the only one which is carried up and expressed externally.

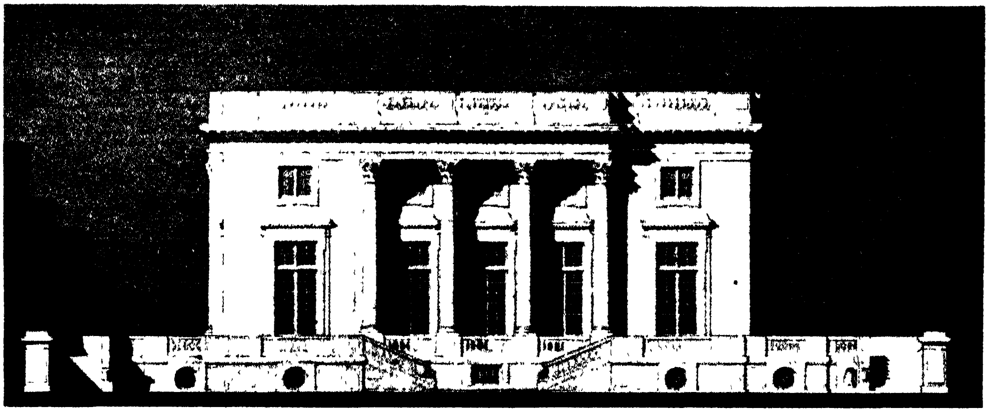


FIG. 116. LE PETIT TRIANON, VERSAILLES

Although the Renaissance proper may be said to have ended before the end of the eighteenth century, the style was continued more or less without interruption, attended, of course, by various revivals as in other countries. Many well-known works were begun under Napoleon, including the Rue de Rivoli opposite the Louvre, the Arc de Triomphe, and the Madeleine (Fig. 117), similar externally to the temples of the Romans, but internally it is divided into three bays, each of which is domed.

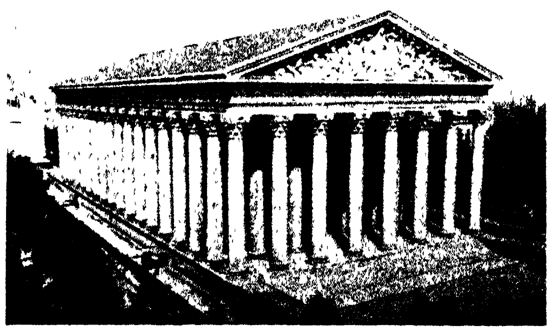


FIG. 117. LE MADELEINE, PARIS

The Renaissance architecture of France, although in the first place an imported style, was ultimately developed along essentially national lines, and is not only interesting, but is one of the most valuable sources of study for the student of architecture.

Chapter VII—RENAISSANCE ARCHITECTURE IN ENGLAND

THE revival of classic art, which began in Italy, reached England during the reign of Henry VIII, and except for the Gothic revival in the nineteenth century, classic architecture, once established, has remained the basic style to the present day.

In its early stages, the Renaissance was largely confined to domestic work, for not only had many churches been built in the fifteenth century, but Henry VIII, when he suppressed the monasteries (1536–40), had both weakened the Church and had distributed its wealth among his courtiers, who devoted considerable attention to their dwellings.

It is interesting to trace briefly the development of the English house, which did not undergo any sudden changes until the seventeenth century, and then only in the case of the larger mansions of the nobility.

Perhaps the earliest dwellings of importance were the mediaeval castles, of which large numbers were erected during the twelfth century. These were built both as residences and military posts, with very little provision for the comfort of the inmates. Their general external characteristics are well known; their massive walls and towers, with few and small windows and doors; their battlemented parapets and keep; and the whole surrounded by a moat and approached by a drawbridge, all conceived with defence as the first consideration. Subsequent developments evidence an increasing desire for comfort and privacy, and as conditions became more settled and the use of gunpowder rendered the older defensive measures futile, the planning of these buildings became more open. Additions to existing castles were usually arranged to enclose a courtyard on three or four sides, a disposition which was retained in the larger buildings of the Tudor and Elizabethan periods, as at Hampton Court Palace.

The irregular arrangement of some of the older buildings is explained by the fact that additions were made to satisfy immediate requirements, and that the site of the original castle, selected as it was with an eye to defence, did not always permit a regular disposition of subsequent additions. The smaller houses of the yeomen were very simple, consisting generally of a common room, or hall, with kitchen and offices at one end and private living rooms at the other.

In these buildings some of the most characteristic phases of English architecture were evolved, and such features as towers, mullioned bay windows, parapets, and fine tall chimney stacks usually possess a pronounced Gothic feeling. The general practice was for the work to be carried out by the various craftsmen, the several trades working separately under the instructions of the client. Throughout there was a marked relationship between materials and design, roof slopes and gables adjusted according to the covering employed, and the craftsmanship in each material being that most suited to its characteristics.

Tudor Period (1485–1558) produced many fine houses and palaces, of which Hampton Court Palace is one of the best known. It is built in 2 in. brickwork of a delightful colour, with diapered panels in darker bricks and with stone dressings. Brickwork, although used by the Romans, had more or less gone out of use until it was reintroduced by the Flemings in the eastern counties in the early fourteenth century.

In timber districts, many "half-timbered" houses were built, those in Cheshire and Lancashire being particularly fine. In stone districts, particularly the Cotswolds, a characteristic tradition was maintained, with stone mullioned windows, oriels, bays, and gables, all retaining the mediaeval feeling in their execution. In the eastern counties, German and Flemish influence is to be seen in the curved gables which are so frequently found on the Continent (Fig. 119).

During the fifteenth century, while the Renaissance was advancing so rapidly in Italy, England adhered to her long established traditions, and it was not until the beginning of the sixteenth century that the signs of the Renaissance began to appear, at first through imported workmen. It has already been noted that Flemings and Germans had settled in the eastern counties in large numbers, but they themselves did not thoroughly understand classic forms, and

although exercising great influence over domestic work in the district named, did little to advance the Renaissance. They were responsible for a great amount of crude work, such as grotesque

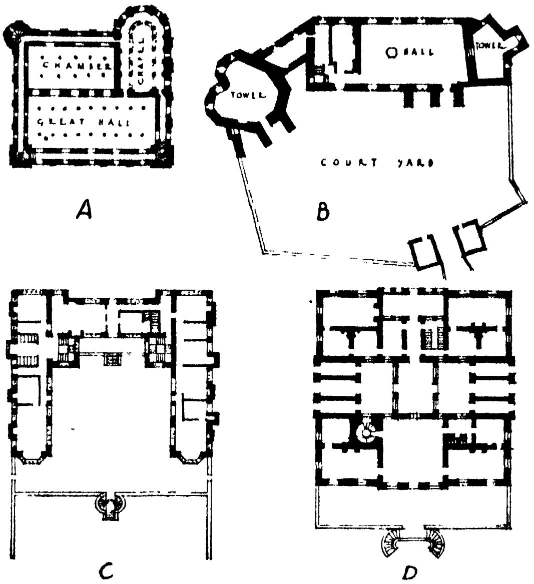


FIG 118
A = The Keep, the Tower of London, eleventh century
B = Stokesay Castle, Shropshire, c 1290
C = Old Wimbledon House (*now destroyed*), c 1588
D = Queen's House, Greenwich, c. 1617

caryatid figures growing out of balusters and deformed Orders,. and their attempts in the classic manner are little more than collections of unrelated and misunderstood detail

For some time it had been the custom to visit Italy for study, and it was inevitable that the splendour of the English Court, under Henry VIII, should attract the Italians. The first artist of note to visit this country was Torrigiano, a fellow student of Michael Angelo, who arrived in England in 1509. His chief work was the tomb of Henry VII in Westminster Abbey. Another artist was Giovanni da Majano, who carried out the terra-cotta medallions which are set in the wall at Hampton Court; other Italians appear to have worked here, particularly in the southern and south-eastern counties. Many buildings of the sixteenth century contain features of obviously Italian influence, but no important complete buildings were erected in the style. Religious differences between Henry VIII and the Pope led to the return of many Italians, and it was probably on this account that some of the more celebrated Italians did not visit England as they had France.

Elizabethan Period. The architecture of this period is transitional. Many of the Gothic features were retained; in fact, in smaller buildings there was no real change for many years.

Certain classic features were introduced, but they were usually in the nature of applied decoration to essentially English buildings, sometimes interesting, at other times crude, but rarely in strict accordance with truly classic principles. Many fine houses were built, and a number of colleges at Oxford and Cambridge. Of the many English builders—they were not generally known as architects until later—no name is better known nor gives room for more discussion than that of John Thorpe. It is not of sufficient moment here to dilate upon the subject, but it is interesting to note that his sketch book, which has been preserved, contains plans of many houses, some quite good, but it is doubtful whether they were all built, though he certainly carried out many important works.

Jacobean Period. Although sometimes used to refer to the architecture of the reign of James I, this name is more commonly applied, sometimes rather vaguely, to the style of interior decoration and furniture of the first quarter of the seventeenth century. The buildings of this period are generally very similar to those of the

FIG. 119. BLICKLING HALL, NORFOLK, 1620

previous period, with the exception of those which will be referred to next.

Inigo Jones (1573–1652). Although planning had advanced to suit the needs of the people, architectural development had been seriously undermined by the efforts of foreign workmen who had imparted only a slight knowledge of

the superficial characteristics of classic art, and there was an obvious need for someone who could lead the way out of that vague, though perhaps interesting, confusion; and it was

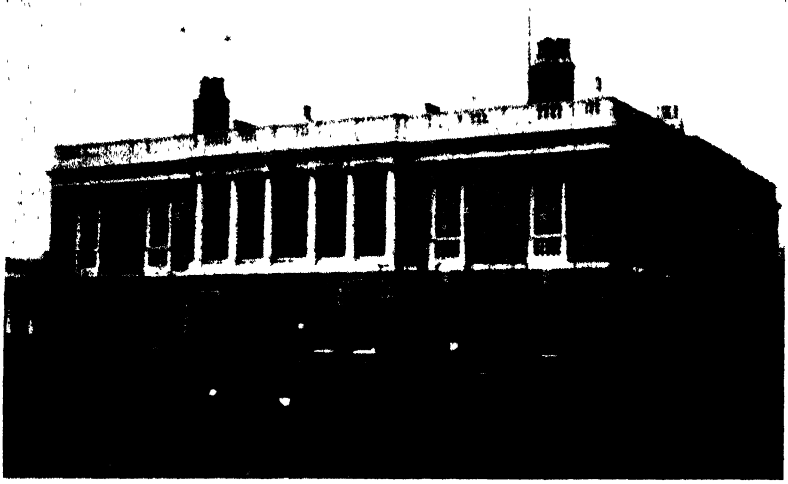


FIG. 120. THE QUEEN'S HOUSE, GREENWICH

Inigo Jones, who, after long study in Italy, was the first exponent of the pure Renaissance in England.

He was born at Smithfield, and began his career as a joiner's apprentice, but later became an artist. As a young man he visited Italy, and was for some time employed at Copenhagen by the King of Denmark. He returned to England in 1604, and spent the next ten years chiefly in the design of scenery for "masques." He again visited Italy in 1613 and remained there over a year, being occupied both in collecting works of art for the Earl of Arundel and in studying the arts. He appears to have been particularly interested in the work of Palladio, whose influence is seen in Inigo Jones's own work. His career as an architect was definitely commenced when he was appointed Surveyor-General to James I in 1615. In 1617 he began the Queen's House at Greenwich (Figs. 118D and 120), and in 1619 the Banqueting House, Whitehall (Fig. 121). The latter was intended to form but a small part of a magnificent scheme which, if carried out, would have produced a building as fine as any built during the Renaissance (Fig. 122), but as has frequently happened, the scheme was abandoned through lack of funds. The Banqueting House is one of the finest works of architecture in this country, and is a great monument to the genius of Inigo Jones, who, in one of his earliest works, showed himself the equal of the great Italian masters. Among his many other works were St. Paul's, Covent Garden (since rebuilt, but substantially as originally designed); Raynham Hall, Norfolk, one of his finest country houses, additions to Wilton House, near Salisbury; houses in Lincoln's Inn Fields; and the Barber Surgeons' Hall. He is also sometimes credited with the design of Coleshill House, Ashburnham House, Westminster, and the river front of King Charles's (Fig. 123) block at Greenwich Hospital, but these were carried out after his death, and it is possible that the latter, at any rate, was the work of his pupil and successor, John Webb.

There is little reliable information concerning the contemporaries of Inigo Jones, due, in some measure, to the very unsettled conditions prevailing between 1640

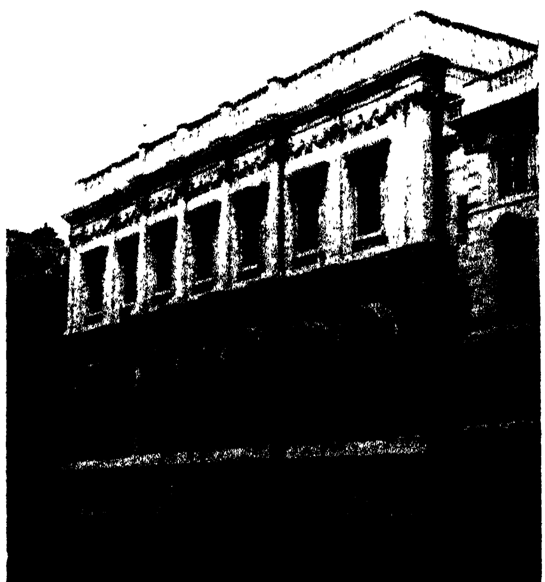


FIG. 121. THE BANQUETING HOUSE, WHITEHALL

and the Restoration. The best known was John Webb. He was born in 1611, and was apprenticed to Jones in 1628, working with him as his assistant until his death. His work shows the influence, but lacks the distinction, of his master's work.

Sir Christopher Wren (1632-1723). The son of a clergyman and a nephew of the then Bishop of Ely, Wren first achieved distinction as a scholar, chiefly in mathematics and astronomy. He does not appear to have had any architectural training prior to his appointment as assistant to Sir John Denham, the Surveyor-General in 1661. He carried out works at Oxford and Cambridge, the Sheldonian Theatre at Oxford providing an opportunity for the

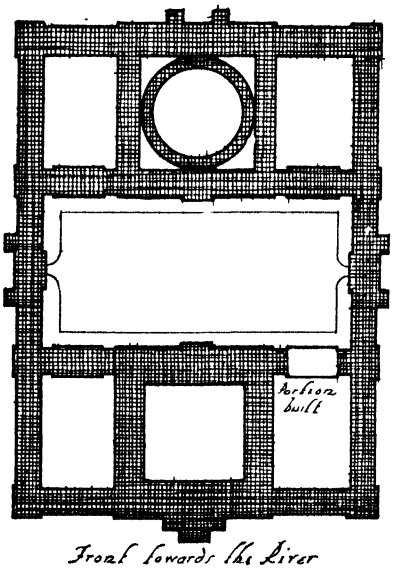


FIG. 122. THE PALACE, WHITEHALL

display of his mechanical ingenuity in the construction of its flat ceiling of 68 ft. in span. The design, however, lacks the refinement of his later work. In 1665 he went to Paris, where he spent six months in the study of works which such men as Lemercier and F. Mansart had completed, and which Le Vau, Perrault, and others were carrying out. On his return he was commissioned to carry out certain restorations to old St. Paul's, but if his drawings, which are preserved in the Library of All Souls, Oxford, are an indication of his intentions, it is indeed fortunate that the Great Fire of London, which occurred in 1666, saved him from carrying them out. Wren succeeded Denham as Surveyor-General in 1668, and found himself with an opportunity unique in the annals of architecture. His first task was to prepare a plan for the lay-out of the city, which was then more or less in ruins, but, unfortunately, this scheme was not even attempted.

St. Paul's Cathedral. Wren next turned his attention to the rebuilding of St. Paul's and the

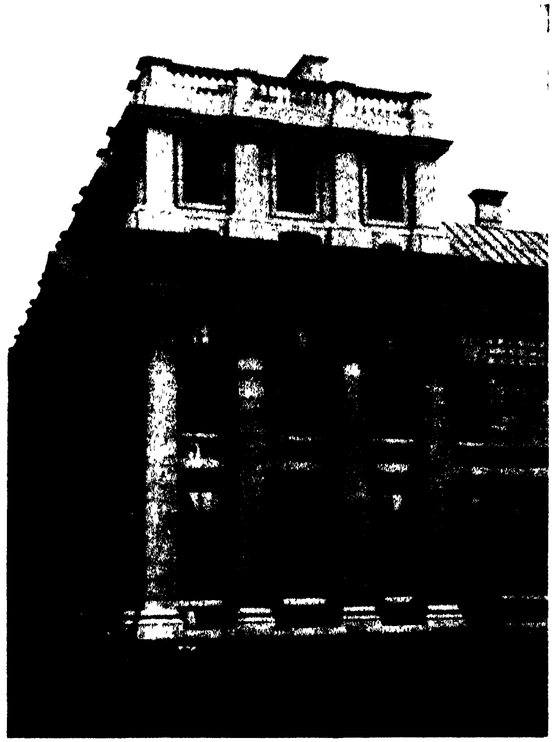


FIG 123 PART OF THE RIVER FRONT OF QUEEN ANNE'S BLOCK, GREENWICH HOSPITAL
(Similar to the work of Jones or Webb)

City churches, the former being, of course, his great work. In most of his works, particularly in London, Wren was fortunate in having the assistance of highly skilled craftsmen who had a thorough understanding of their work, including such artists as Grinling Gibbons, the wood-carver, Cibber, the stone-carver, and Tijou, the celebrated smith, who executed the wrought-iron screens, and who also designed the beautiful gates for Hampton Court. Attempts had been made to repair the ruins of the old cathedral, but in 1668 the work collapsed, and Wren was commissioned to prepare designs for a new building. His first scheme, an octagonal building about 300 ft. across, was not accepted,

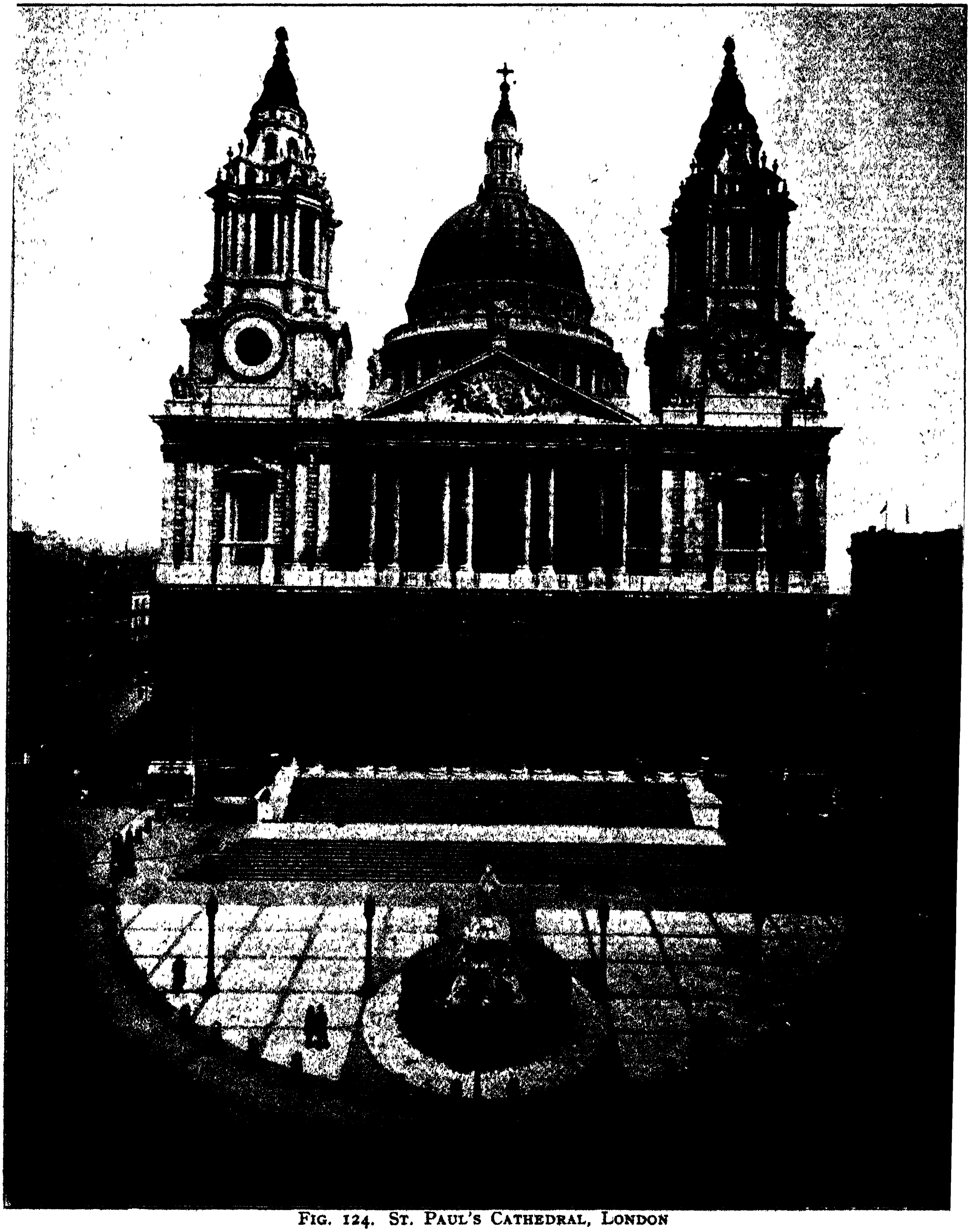


FIG. 124. ST. PAUL'S CATHEDRAL, LONDON

chiefly on account of its break from the traditional English plan-form with nave, transepts, choir, and aisles. The next design was accepted in 1675, the warrant authorizing Wren to make

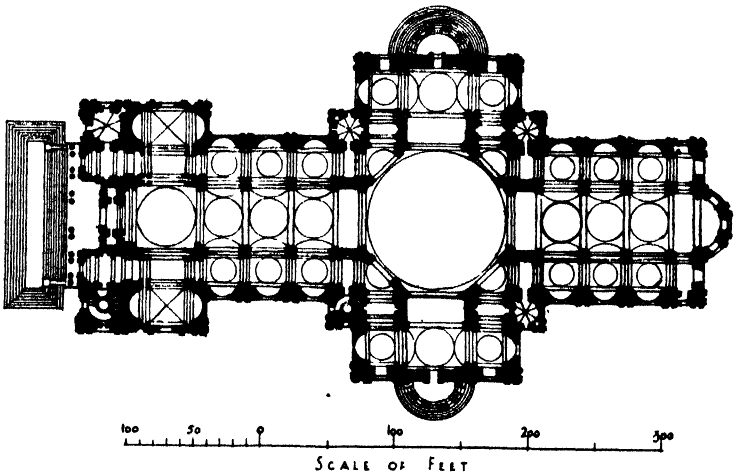


FIG 125. ST PAUL'S CATHEDRAL, LONDON

such variations to the detail as he thought proper from time to time. Although the plan of this design was very similar to that executed, the central dome consisted of a most peculiar double dome and steeple combined. Fortunately, however, Wren took advantage of the freedom which his commission allowed, and he made the adjustments which produced the building as it is to-day (Fig. 124).

The foundation stone was laid in 1675 by Wren, and the final stone on the lantern by his son thirty-five years later. The most striking feature is the dome, which, although smaller than that of St. Peter's, Rome (it is 110 ft. at the base of the drum and 102 ft. at the springing of the dome), is probably the finest existing for beauty of outline and the fine manner in which it builds up from the structure below. Its construction is interesting, for there are actually three domes. The inner one is of brickwork about 18 in. thick, and the outer is framed in timber and covered with lead, supported on an intermediate conical dome, also of brickwork, which also supports the huge stone lantern, the estimated weight of which is 700 tons.

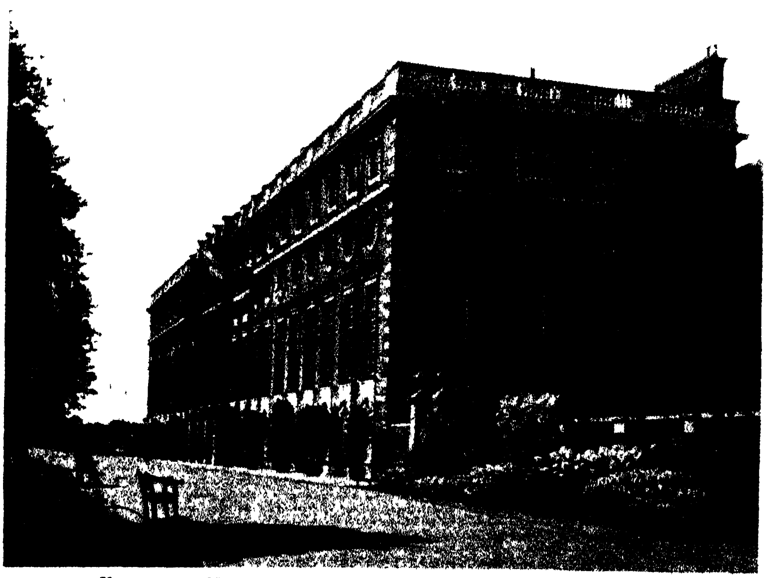


FIG. 126. HAMPTON COURT PALACE; EASTERN FRONT

The City Churches. Between 1670 and 1711 Wren also designed about fifty churches, many of which show great skill in planning on difficult sites. The general arrangements were made to conform to the Protestant ritual, in which the arrangement of seating accommodation, so that the congregation might hear the preacher, was the chief consideration. Many ingenious arrangements of a few columns were adopted to provide impressive interiors, while externally their stone or brick façades are usually very fine in their simplicity and dignity. Many of these churches were tucked away behind shops and houses, and their position was marked by a tower or spire, a feature which is one of the most interesting in these buildings. Those of St. Mary-le-Bow and St. Bride's, Fleet Street, are the best of those constructed entirely of stone, while that of St. Martin's, Ludgate Hill, a lead-covered

spire rising from a stone tower, is one of the best of the composite types.

Wren built a number of buildings of a domestic and public character, including work on the three palaces at Hampton Court (Fig. 126), Kensington, and Winchester. The first is perhaps the best known, consisting of important blocks on two sides of his Fountain Court. The façades are of red brickwork with stone dressings, and, except in a few minor details, this is one of his most successful works. Some of the craftsmen employed on St. Paul's also worked here. At Kensington he made certain alterations to the Palace, and is also believed to have carried out the Orangery. His palace at Winchester, originally intended to rival the great Palace at Versailles, was never completed, and has since been used as barracks and altered considerably. Perhaps his finest public building is Greenwich Hospital, where he carried on the work commenced by Inigo Jones and Webb, and was primarily responsible for what is undoubtedly one of the finest groups in London. He repeated the block which already existed on the river front (Fig. 123), and added two others to the south (Fig. 127), the whole being arranged on an axis passing through the Queen's House, completed by Jones. Wren was followed at Greenwich by Vanbrugh, Hawksmoor, and others, but in the main their work is very inferior.

Other well-known buildings are Chelsea Hospital; Morden College, Blackheath; Temple Bar, London (now removed to Theobald's Park); and the Monument, London Bridge, built in 1671 to commemorate the Fire of London. It is interesting to note that Wren designed a few buildings in the Gothic manner, one of which, the tower of St. Michael's, Cornhill, is believed to have been his last work.

He died in 1723 at the great age of 90, after a career spent in placing the Renaissance architecture of England on a firm foundation. Towards the end he was troubled very much by the intrigue of rivals, and upon his dismissal from the post of Surveyor-General in 1718, he retired to his house at Hampton Court.

Inigo Jones and Wren had few serious rivals, but many famous architects had established themselves by the beginning of the eighteenth century. With the Renaissance movement so far advanced on the Continent, and with facilities for travel and interchange of ideas so much improved, it was inevitable that the lead of Jones and Wren should not be followed without question, and although traditions were more or less maintained in smaller domestic work, great changes took place in the many monumental country mansions and public buildings which were carried out during the century. It had long been the custom to look upon a taste in artistic affairs as an essential quality in the culture of the aristocracy, and a grand tour of

FIG. 127. GREENWICH HOSPITAL
(One of the twin domes and colonnade by Wren)

Europe was made by many, with their enthusiasm finding expression in the collecting of antiques and works of art. These travellers were frequently accompanied by their architects, who were thus enabled to gain first-hand information concerning classic architecture. Wealthy gentlemen did much to foster the development of architecture, both by the financing of archaeological expeditions and by the encouragement of fine architecture. Hitherto little reliable information on classic architecture had been available, but by the middle of the century many works were published, including a number of Palladio's drawings of Roman buildings, issued in 1730 at the instigation of the Earl of Burlington. These were followed by the first of the famous engravings by Piranisi in 1741, many illustrated

works dealing with the re-discovered cities of Herculaneum and Pompeii from 1750 onwards, the first volume of *Antiquities of Athens* by Stuart and Revett in 1762, and drawings of Diocletian's Palace at Spalato by Robert Adam and others in 1764. There resulted a better understanding of classic form, often obtained direct from antique origins, and especially

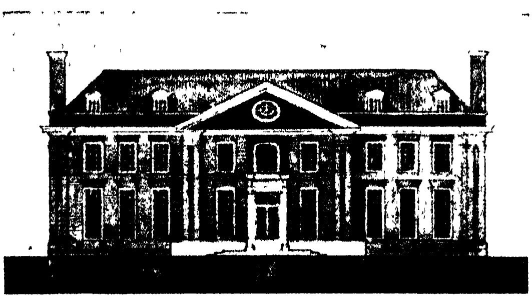


FIG. 128. BRADBOURNE, KENT, *c.* 1713

evidenced in the popularity of the pedimented portico.

Concurrent with this vigorous movement in architecture, forms of government were developed, and commerce grew in importance, both creating a demand for new types of building and changes in the old, and many government and municipal buildings, exchanges, museums, prisons, and similar institutions were erected.

Houses. The modest dwellings of the middle classes are in many ways more interesting than the large mansions, for they show the carrying on of the traditional architecture of the previous century; they are often referred to as the Queen Anne and Georgian houses. Simply and compactly arranged on a square or rectangular plan form, they owe much to the delightful colour of their red brick walls with stone dressings and white painted joinery (Fig. 128). Characteristic features are cornices at the eaves, simple hipped roofs, with perhaps a pediment over a central projection, plain or panelled chimney stacks with a small capping, sash windows with the frames usually set flush with the outside face of the wall, and a concentration of interest on the main entrance, with pilasters or columns supporting a hood. Examples of this most interesting phase of English architecture are to be seen in nearly every town which was established during the period under review.

Country Mansions. Sometimes surpassing in splendour and size even the royal palaces, the country houses of the aristocracy show more clearly the tendencies in the development of the Renaissance. It has been pointed out that the nobility were often enthusiastic patrons of architecture, and in these circumstances it is not surprising that their houses were often conceived very largely for effect. Many of these imposing buildings have interesting plans, with wings containing such

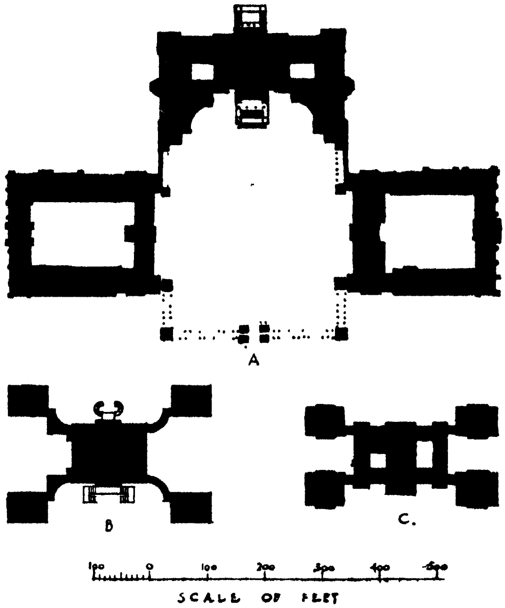


FIG. 129

A = Blenheim Palace *B* = Kedleston Hall
C = Holkham Hall

accommodation as chapel, stables, library, kitchens, etc., grouped on either side of the main blocks (Fig. 129). In detail these plans sometimes show serious defects in circulation and badly shaped and lighted rooms.

Churches. Many churches were built during the earlier part of the century, the Act of Queen Anne (1708) authorizing the erection of fifty such buildings. These follow somewhat the precedent of Wren, both in general planning and external treatment, with sometimes a classic pedimented portico, as at St. Martin-in-the-Fields, and St. George, Bloomsbury.

The following are some of the better known architects of the eighteenth century—

Nicholas Hawksmoor (1661–1736). At the age of 18, he became Wren's pupil, and worked with him for about thirty years, later assisting Vanbrugh at Castle Howard and Blenheim. His best works are churches, the following being the most important: St. Mary Woolnoth; St.

George Bloomsbury; St. Anne, Limehouse; St. George in the East; Christ Church, Spitalfields; and St. Alphege, Greenwich.

Sir John Vanbrugh (1666–1726). In many ways Vanbrugh is one of the most interesting of Wren's contemporaries because of his influence on the work of the early eighteenth century. His early life and training do not appear to have indicated his ultimate career, but success in literature and popularity at Court gave him a reputation which he turned to account in architecture. His work was original and full of vigour, but it betrays a certain enthusiasm for monumental effect, which often resulted in a disregard of usefulness. He is best known for his great country houses, the finest being Blenheim Palace for the Duke of Marlborough, the plan of which shows considerable advance, although containing some features which were sacrificed for effect externally. Other important buildings were Castle Howard in Yorkshire and Seaton-Delaval, Northumberland.

James Gibbs (1683–1754). After extensive travel abroad, he was helped by Wren and others and was appointed to build some of the churches authorized by the Act of Queen Anne. He was responsible for two of the best known churches in London: St. Mary-le-Strand (Fig. 131) and St. Martin-in-the-Fields. The former is very largely in the manner of Wren, although somewhat overcrowded with ornament. The Senate House, Cambridge, and the Radcliffe Library at Oxford are among his best later works. He published some *Rules for Drawing the Several Parts of Architecture*, and other works.

FIG 130. ST ALPHEGE, GREENWICH

FIG. 131. ST. MARY-LE-STRAND, LONDON

The Earl of Burlington (1695–1753). In an age when the patronage of the aristocracy counted so much for the success of many architects, it is not unnatural that these patrons should be associated with architectural history and even credited with the design of certain buildings. The Earl of Burlington, who was undoubtedly keenly interested in architecture, is by some considered to have designed the

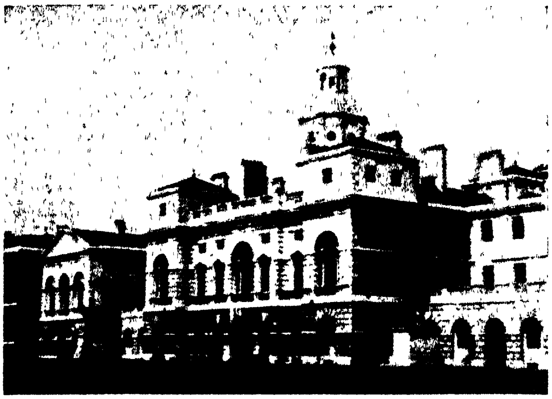


FIG. 132. THE HORSE GUARDS, WHITEHALL

front of Burlington House, a villa at Chiswick, and other buildings; but Campbell, a contemporary architect and writer, claims authorship of the former, and it is quite likely that these buildings were designed by either Campbell, Kent, or Leoni, all of whom were at some time the paid associates of the Earl.

William Kent (1684–1748). He began his career as a coach-painter, but after travelling Italy he attracted the attention of the Earl of Burlington, whose service he entered and with whom he lived until his death. Although best known as an architect, he showed great versatility in the design of the furniture and accessories of houses, but in general such efforts were not successful. Perhaps the best of his important buildings was the Horse Guards, London (Fig. 132), an interesting and somewhat picturesque group, commenced in 1742 and completed after his death. He also designed Devonshire House, now demolished, and Holkham in Norfolk.

John Wood (1704–1754). His most important building was Prior Park, a fine mansion near Bath, but of particular interest was his work in the city, which includes fine terraces of simple houses arranged in squares and crescents.

George Dance (1698–1768). In the capacity of "Clerk of the City Works" Dance carried out a number of buildings in the city, and is particularly noted for the Mansion House, commenced in 1739. Although not perhaps a brilliant building, it is suitable in its scale for purpose and its surroundings, and is typical of "pediment and portico" architecture, popular at this time.

His son, known as Dance "the Younger," designed the old Newgate Prison (now demolished) a building particularly expressive of its purpose.

Sir William Chambers (1726–1796). Although originally destined to enter his father's mercantile business, he abandoned this idea at the age of eighteen and went to France and Italy, where he spent some years in the study of architecture. For a number of years after his return he was occupied with the carrying out of a number of smaller buildings, in particular of *casinos* or summer houses in the gardens of

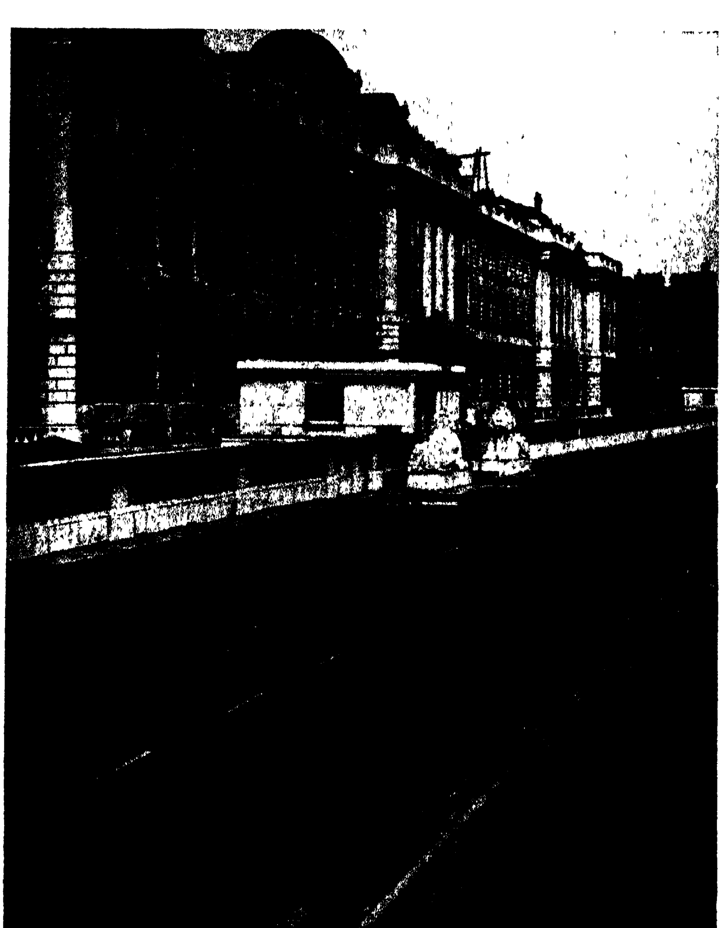


FIG. 133. THE RIVER FRONT, SOMERSET HOUSE, LONDON

noblemen's houses. His great work was Somerset House (Fig. 133). The frontage of about 500 feet towards the river is possibly the finest of its kind in London, and the plan, with its fine courtyard, is very well arranged and provides an excellent view from the Strand entrance. The buildings were completed by Sir Robert Smirke and Sir James Pennethorne.

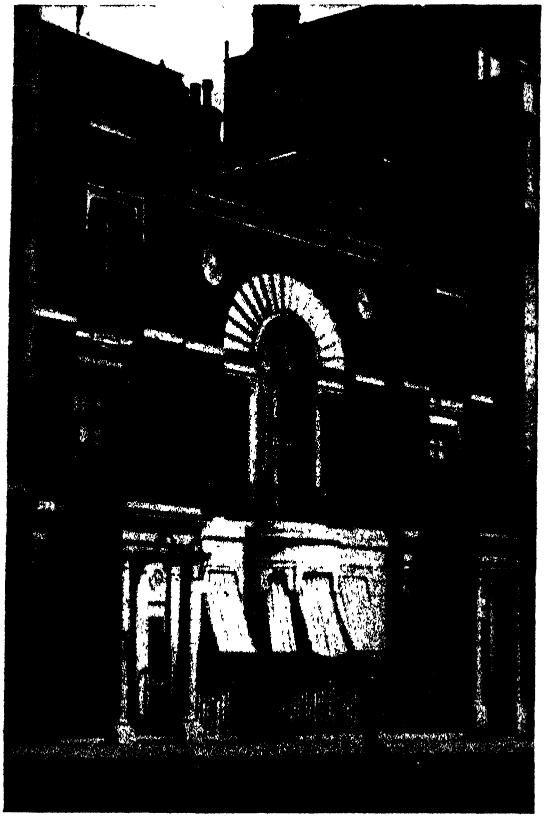


FIG. 134. THE BOODLES CLUB, LONDON

James Gandon (1742–1823). A pupil of Chambers, he was successful in competitions at an early age, and carried out, among other buildings, the Custom House and the Four Courts, Dublin.

Robert Adam (1728–1793). The brothers Adam, architects and in some cases builders, have perhaps attracted most notice through the distinctive style of interior decoration which bears their name. Its usually refined detail shows clearly the influence of the revived interest in antique architecture. Robert, the best known of this family, designed many buildings, including Stowe House, Bucks, Kenwood and Sion House, both near London, University Buildings, Edinburgh, and a number of houses in London, including the Adelphi Terrace. The Boodles Club (Fig. 134) is a typical example.

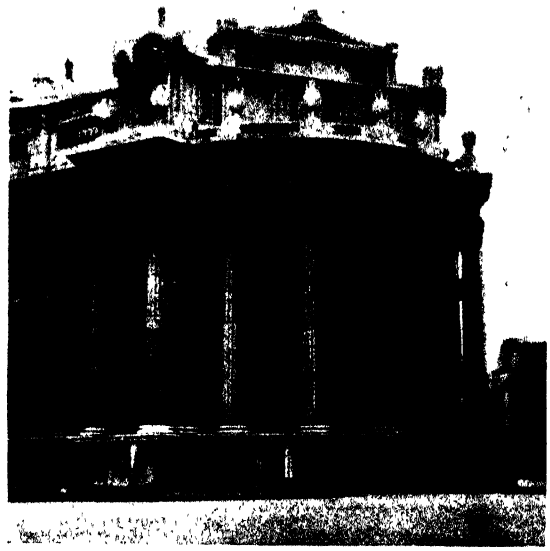


FIG 135. THE BANK OF ENGLAND, LONDON
"Tivoli Corner"

Sir John Soane (1750–1837). As a student he was awarded the Royal Academy Gold Medal, and was sent to Italy for study. On his return he was appointed architect to the Bank of England, the completion of which constituted his great work. The design of some of the enclosed courtyards and the interiors shows great originality, although perhaps at times eccentric.

Many buildings erected during the latter part of the eighteenth century are to be seen throughout Great Britain, for information concerning which readers are referred to an exceptionally fine work—*Monumental Architecture in Great Britain and Ireland during the XVIII and XIX Centuries*, by A. E. Richardson.

Chapter VIII—NINETEENTH-CENTURY ARCHITECTURE IN ENGLAND

ARCHITECTURAL development during the nineteenth century consisted very largely of a series of revivals of the various phases of Classic art and of the Gothic styles, the latter, however, ultimately giving way to a return to Classic principles, which have since more or less controlled architecture. It has been seen that the Renaissance movement was in the first place inspired by Roman and Italian examples, in particular by Palladio and his writings; but with the investigations of Stuart and Revett in Greece, and the subsequent publication of their work—*Antiquities of Athens*—in 1762, there began an enthusiastic seeking after knowledge of the works of the ancient Greeks, which was to spread throughout Europe. The influence of this movement was first evidenced in a feeling for refinement and in the appearance of Greek detail, which was blended with the Palladian version of Classic art then in vogue. One of the earliest buildings to show this tendency was No. 15 St. James's Square (Fig. 136), designed by James Stuart, who, unfortunately, did not practise extensively.

FIG. 136. NO. 15 ST. JAMES'S SQUARE, LONDON

During the Napoleonic Wars, which more or less closed Europe to travellers, English architects made Greece and Asia Minor their training grounds and, aided frequently by the influential Dilettanti Society, published the results of their researches. The famous Elgin collection, which included fragments from the Parthenon, were brought to England early in the century, and attention was almost completely centred on the re-discovered Hellenic arts. The transition from the Roman to the Greek phase was more or less completed with the beginning of the new century. Many buildings erected during the latter part of the eighteenth century show the gradually increasing influence of Greek origins, in particular those of Soane and the Adam brothers. Although sometimes of great dignity and beauty, the work of the Greek revival failed generally in that exactitude of reproduction too frequently took the place of reason and suitability, and buildings were, in consequence, lifeless and meaningless.

One of the first exponents was William Wilkins (1778–1839). Among his many buildings were St. George's Hospital and the National Gallery, and in association with Gandy-Deering he designed University College, Gower Street, London. His work shows him to have been thoroughly acquainted with Greek detail, but lacks effectiveness in its composition.

Sir Robert Smirke (1781–1867) carried out some of the most important works of the period. A pupil of Soane's and a student at the Royal Academy Schools, he later travelled extensively. His greatest work was the rebuilding of the British Museum, the well-known main façade of which consists of ranges of fine Greek Ionic columns.

One of the most distinguished architects of the nineteenth century was Decimus Burton (1800–1881). Perhaps his most interesting building was the Athenaeum Club in Pall Mall (Fig. 137), built between 1829 and 1830. (The attic story was added later.) The simplicity of


FIG. 137. THE ATHENAEUM CLUB, PALL MALL


FIG. 138. THE FISHMONGERS' HALL, LONDON

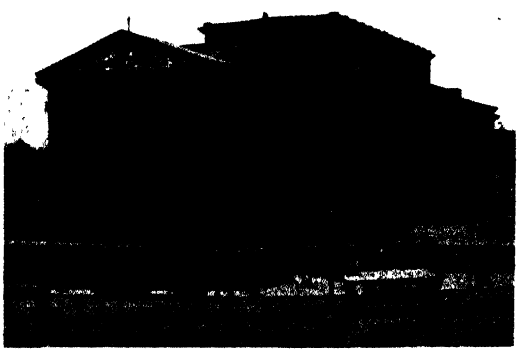


FIG. 139. ST. GEORGE'S HALL, LIVERPOOL

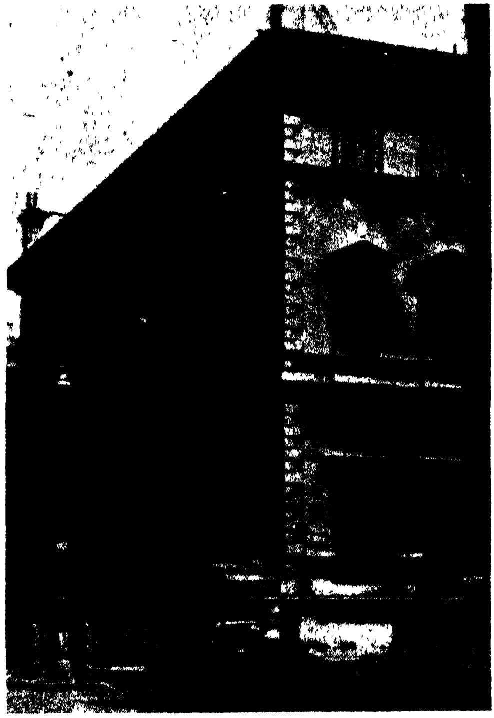


FIG. 140. THE TRAVELLERS' CLUB, PALL MALL

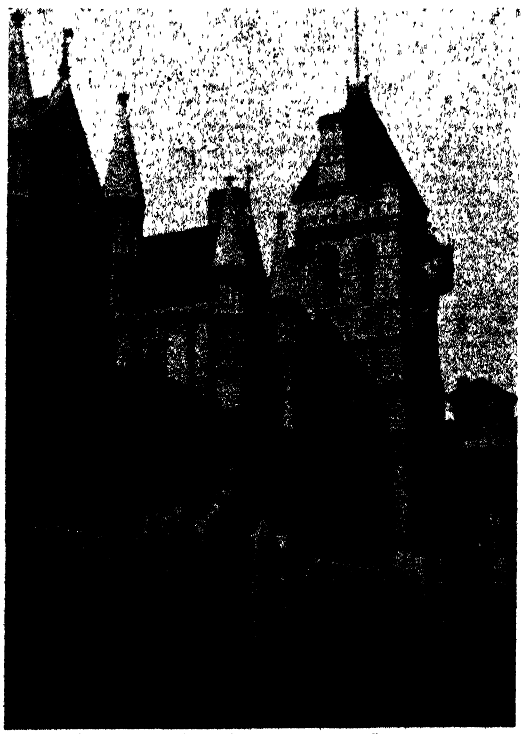


FIG. 141. THE LAW COURTS, LONDON

the massing and astylar façades is a pleasant relief from the customary colonnaded and pedimented buildings. He also designed the Triumphal Arch on Constitution Hill, the Screen at Hyde Park Corner, and a number of the Lodges to Hyde Park.

The Fishmongers' Hall, London Bridge (Fig. 138), is a characteristic example of the work of the period; completed in 1833, it was the only important building of a little known architect, Henry Roberts.

A remarkable example of the Greek Revival is St. Pancras Church. This was designed by a family of architects, the Inwoods, and is a combination of features from the Erechtheion, with a steeple based on the Temple of Winds, Athens.

One of the finest buildings of the Greek revival was the High School at Edinburgh, designed by Thomas Hamilton. It is dignified in massing and refined in detail; the main entrance is based on the Thesion at Athens.

A prominent architect of the early nineteenth century was John Nash (1752–1835), whose work includes Buckingham Palace (since, substantially altered) and the Marble Arch, originally situated in front of the Palace. He is perhaps best known for his town-planning schemes and designs for streets and terraces.

One of the finest monumental buildings in Europe is St. George's Hall, Liverpool (Fig. 139). It was the only important building of Harvey Lonsdale Elmes (1814–1847), designed after his success in competition for the Hall and the Assize Courts; his scheme, as executed, combined these buildings. Unfortunately, he died before the building was finished, and it was completed by Professor Cockerell (1788–1863), one of the outstanding personalities in a movement towards freer application of Classic character and detail. The exterior possesses Classic dignity at its best, and the interior of the great hall is reminiscent of the grandeur of the Roman Baths.

The works of Sir Charles Barry (1795–1860) are a striking indication of the eclecticism which prevailed at the middle of the century. Although essentially of the Classic school, and carrying out most of his works in the manner of the Italian Renaissance, he also designed the Houses of Parliament. Here, however, it is evident that the building was conceived with Classic feeling, although detailed and decorated with very carefully handled Gothic detail. One of his best known buildings is the Travellers' Club in Pall Mall (Fig. 140), in which the Orders are definitely abandoned in favour of a very refined astylar façade of obvious Italian influence.

The Gothic Revival. In a country so rich in examples of mediaeval architecture, the Gothic style could never be totally abandoned; but, although a number of ecclesiastical buildings had been carried out from time to time since the introduction of Classic art into England, it was not until the middle of the eighteenth century that a serious attempt was made to revive the style in other buildings. Early in the nineteenth century, however, attention was attracted by the publication of works by Pugin and others. The movement made progress, until in the thirties there was an open warfare between the followers of the two revivals.

Pugin (1812–1852) had acquired great knowledge of mediaeval art from his father, and carried out a large number of churches, schools, and houses; he assisted Sir Charles Barry in the Houses of Parliament.

Of the many architects who worked in the Gothic manner, the following were of importance—

Alfred Waterhouse carried out the Prudential Offices, Holborn, and the Natural History Museum, South Kensington.

G. E. Street (1824–1891), designed, among other buildings, the Law Courts, London (Fig. 141). It is probable that this building, completed in 1884, proved that the Gothic style was not suitable for modern buildings other than churches, and led to its ultimate abandonment.

Sir Gilbert Scott (1810–1877) designed a number of churches, some of which are very fine, St. Pancras Station, and the Albert Memorial.

Although the Gothic school triumphed for a short time, its supremacy was challenged and destroyed by the decision, after a number of disputes, to build the Home and Foreign Offices (1860–1870) in the Classic manner. This work was entrusted to Sir Gilbert Scott, but—as was to be expected from one whose sympathies had been with the Gothic styles—the result was by no means satisfactory.

The architecture of the last part of the nineteenth century is expressive of the catholicity of taste which prevailed. Such a state of affairs was inevitable, having in mind the increased facilities for travel and the spread of knowledge. Although many notable buildings were erected, architecture consisted for the most part of a series of fashionable revivals, some of them merely imitative, others interpreted in a free manner which was often original but not meritorious.

Chapter IX—TWENTIETH CENTURY ARCHITECTURE IN ENGLAND

THE architecture of the twentieth century in England may be considered in two main divisions. The first consists of those buildings which show a more or less definite continuation of the classical traditions of the nineteenth century, while the second includes the many types of structure which have resulted from the influence of Continental movements or from our own experiments in the use and expression of modern materials.

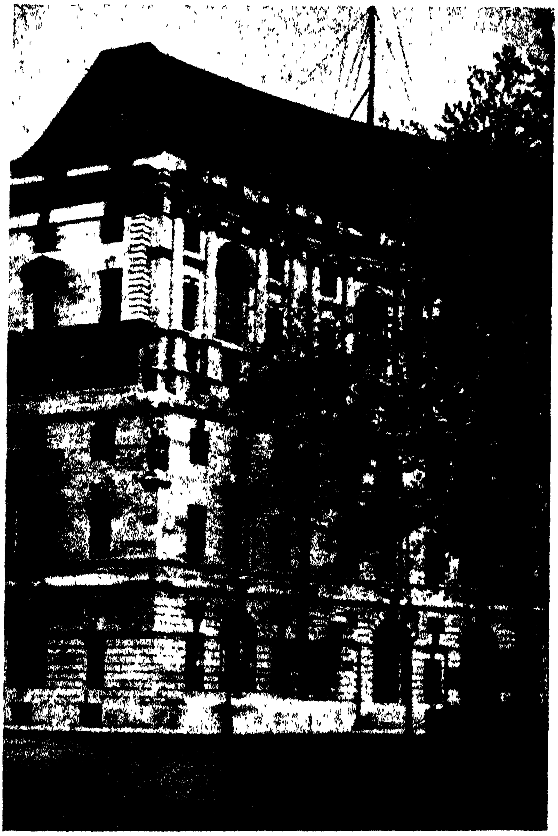


FIG. 142. BRITANNIC HOUSE, LONDON

In Great Britain there has, in fact, during the past twenty years been a "battle of the styles." At one extreme have been the classic traditionalists and at the other end the "functionalists." The latter contended that if anything, a building or an aeroplane, was of maximum efficiency then it was also automatically beautiful. Few, if any, architects now take this extreme view, though there is no doubt that on the whole architectural design now relies more on structure, function, and the proper handling of materials and masses than on applied ornament, particularly of a classic character. Indeed, most buildings designed to-day represent some compromise between the two extremes. Dudok has had great influence in establishing this compromise, as will be seen by comparing the illustrations of his Hilversum Town Hall, Holland, with the Freemasons' Hospital, London, and the school at Greenford.

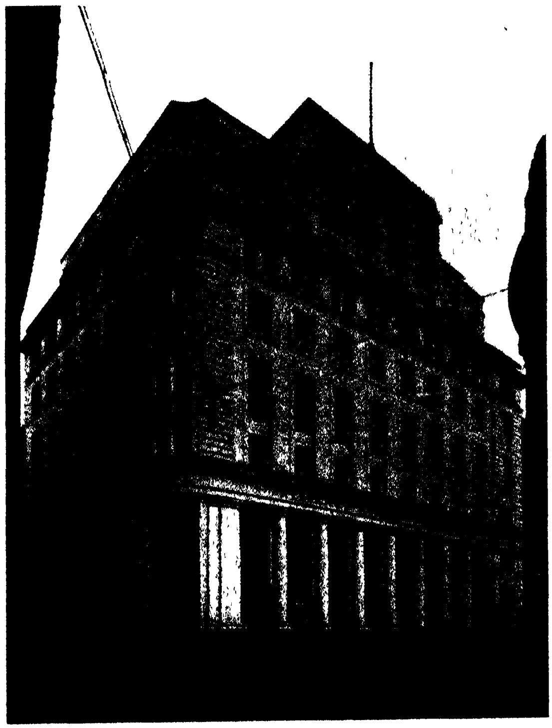


FIG. 143. THE ALLIANCE ASSURANCE BUILDING, LONDON

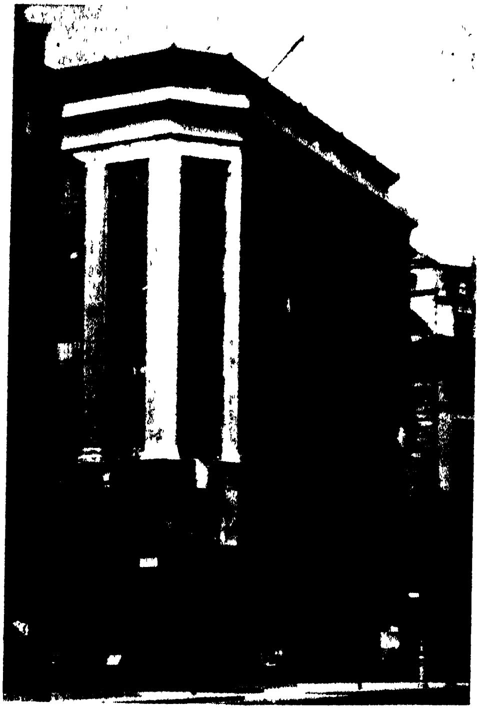


FIG. 144 THE KODAK BUILDING, KINGSWAY

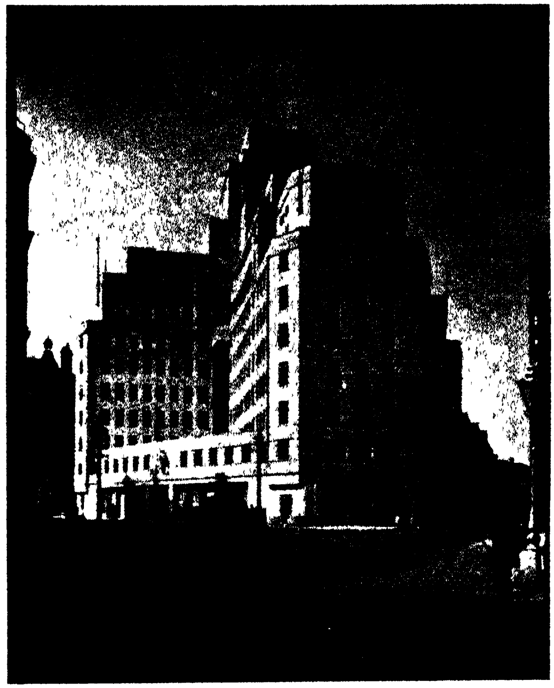


FIG 146. THE "UNDERGROUND" BUILDING, LONDON

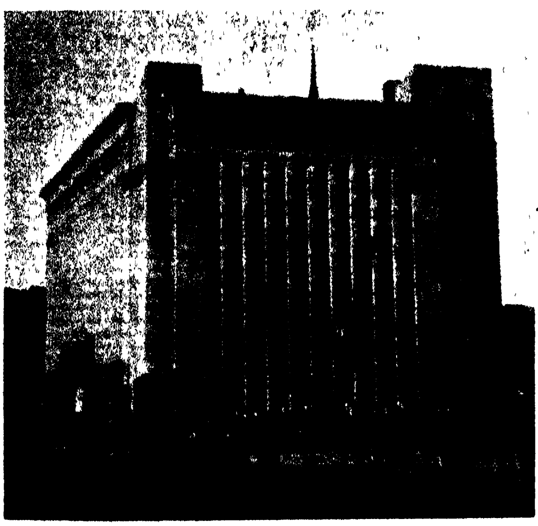


FIG. 145. ADELAIDE HOUSE, LONDON BRIDGE

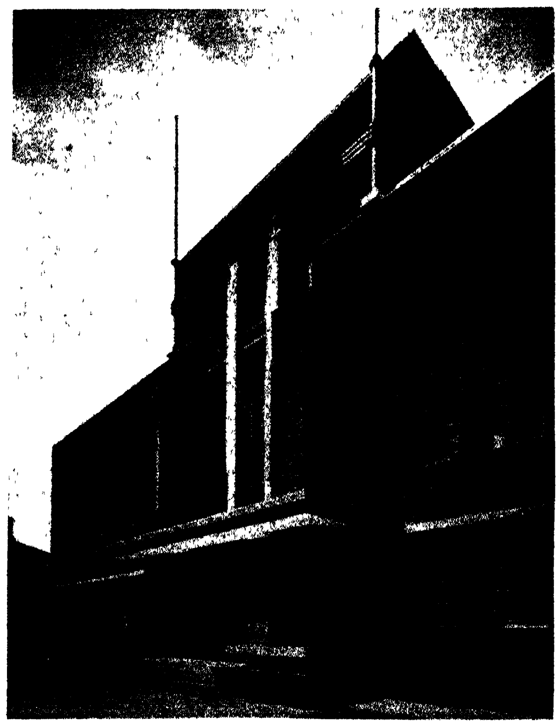


FIG. 147. FREEMASONS' HOSPITAL, LONDON

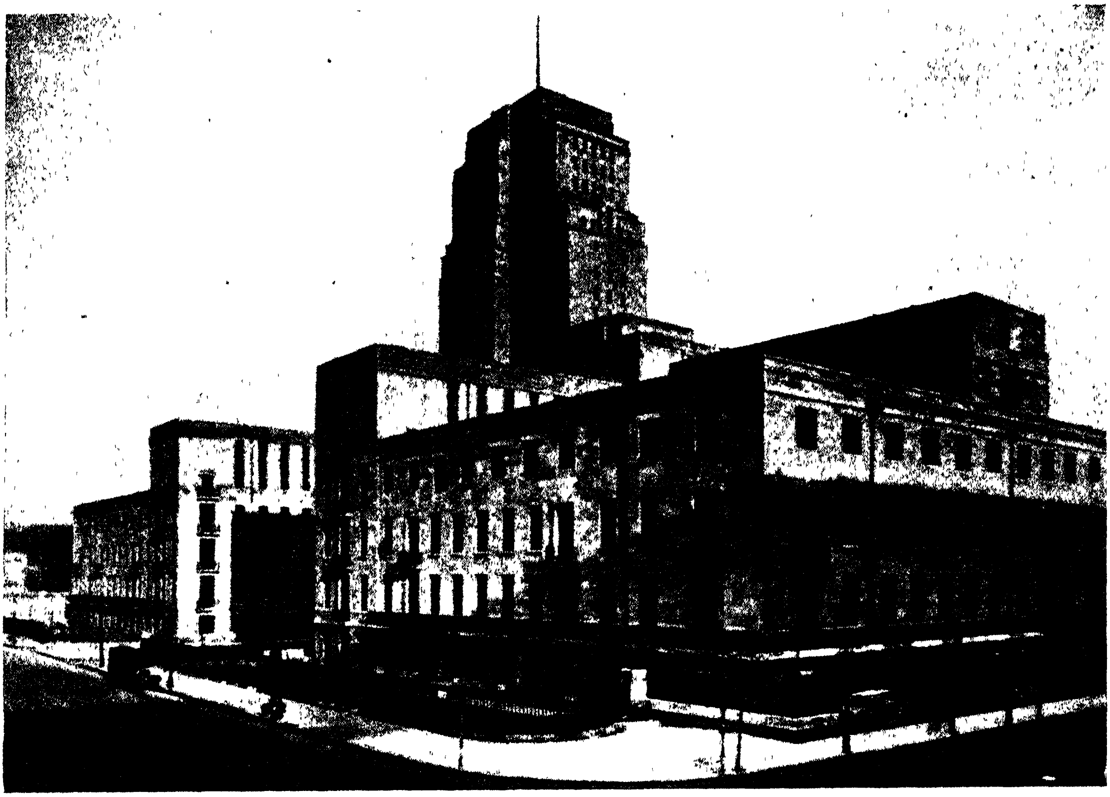


FIG. 148. LONDON UNIVERSITY BUILDING

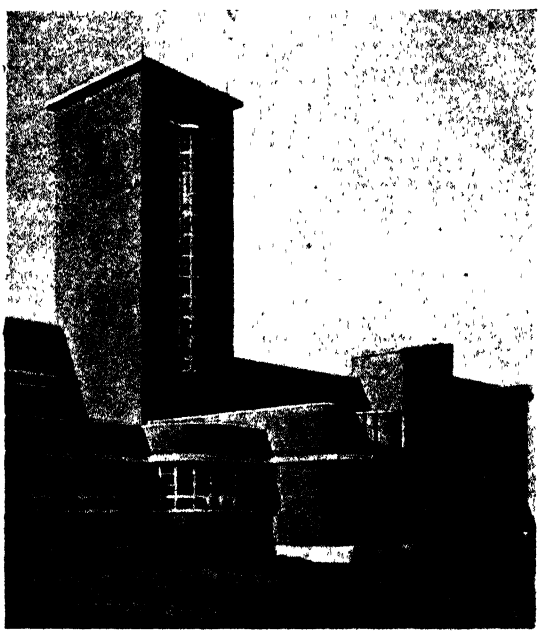


FIG. 149

FIG. 150. "DAILY EXPRESS" BUILDING, LONDON

The rise of the twentieth century in England saw architectural activities controlled for the most part by men who sought to carry on the

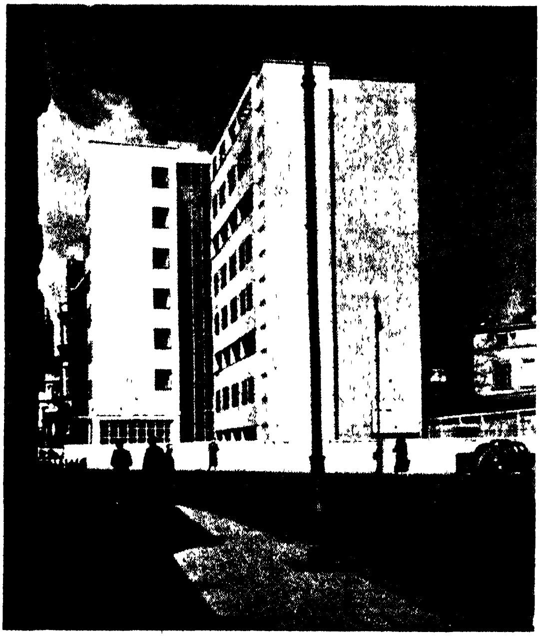


FIG 151. FLATS AT PALACE GATE, LONDON

traditions of the nineteenth century. Design was inspired by historical examples, and nearly always failed to express adequately the proper use of contemporary materials and methods of construction. Such a state of affairs was the inevitable result of the system of training, and of a very conservative outlook upon architecture as a whole, despite the world-wide sources of inspiration which were opened up by improved means of travel and illustration.

An outstanding personality was Norman Shaw, who carried out many town and country houses, and the New Scotland Yard Building. One of his latest and most interesting works was the façade of the Piccadilly Hotel, which, despite many peculiar details, must be accepted as a real attempt to solve a then modern problem.

Perhaps the greatest contemporary exponent of the more or less traditional manner was Sir Edwin Lutyens. Much of his work may not satisfy those whose outlook is strictly utilitarian, but his fine sense of proportion and scale, freshness of detail, and originality of composition, have made many of his buildings of definite historical value. An outstanding example is Britannic House (Fig. 142), in which classical *motifs* have been adopted with great success.

Another building of interest is the Alliance Assurance Building (Fig. 143) which shows a decided preference for traditional features, with perhaps closer regard for simplicity in elevational treatment, and the provision of adequate window areas.

Although the influence of Renaissance architecture is still very profound, many buildings have been erected during this century which show an increasing desire to gain effect by the skilful arrangement of simple masses, with adequate regard for the more logical use of steel frame construction and economy in decoration.

An early example of this phase was the Kodak Building (Fig. 144). The main structural lines of this building are expressed in a straightforward manner, with the simplest possible detail not being related to any particular historical style. Of similar character are Adelaide House (Fig. 145), and the new Underground Building at Westminster (Fig. 146). The latter building should be studied, particularly in plan, as one in which the maximum amount of well-lighted floor space has been provided by extremely skilful planning.

The new London University Building (Fig. 148) claims a place in this review if only for its

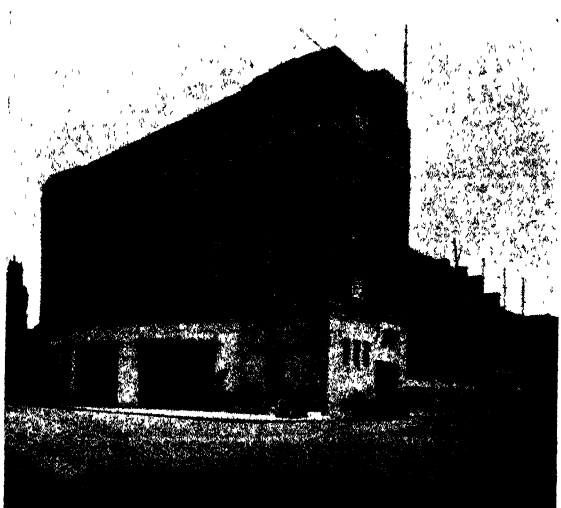


FIG. 152. THE HORTICULTURAL HALL, LONDON

size and civic importance. Like the Underground Building by the same architect, it is not related to any historical precedent, although

its detail might be regarded as an "austerity" version of the classical manner. It is essentially an individualist's building with an occasional disregard of the commonplace, particularly in the spacing of the third floor windows, and in the scale of the openings to the central tower.

In an essentially different category is the *Daily Express* building (Fig. 150). This building, while it is not likely to rank as one of definite historical importance, indicates very clearly the trend of modern thought in architecture. The structural possibilities of steel and reinforced concrete are exploited to the utmost, in an attempt to provide a maximum of window area, while sheet glass takes the place of the more traditional brick and stone as a wall material.

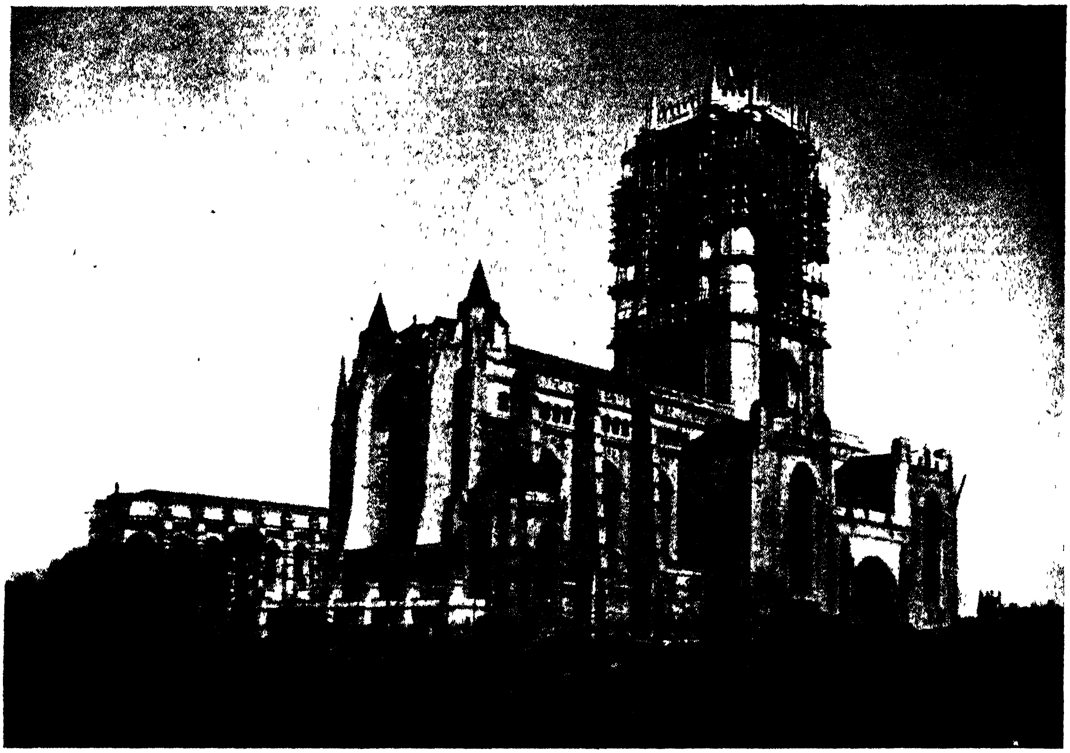


FIG 153. ANGLICAN CATHEDRAL, LIVERPOOL

The block of flats at Palace Gate, London (Fig. 151), reflects another modern approach, in which full use is made of modern constructional materials and devices in giving free and fanciful expression to planning requirements.

The Horticultural Hall (Fig. 152) by Easton and Robertson is of particular interest; its main elevation shows a very dignified handling of simple brickwork, with original and well-placed decorative elements. This building may well be an indication of the manner in which a national style will develop.

It was inevitable that the architecture of this country should be influenced to a very large extent by contemporary work on the Continent and elsewhere. The new Freemasons' Hospital (Fig. 147) shows in its elevational treatment the influence of contemporary architecture in Holland: this building develops from a fine plan, and although the accommodation is of necessity of a strictly utilitarian nature, it has been so adjusted as to produce a monumental effect, in which the skilful arrangement of simple window openings in plain wall surfaces is an important factor.

The Secondary School at Greenford (Fig. 149) is typical of many excellent school buildings in Middlesex and elsewhere, and shows the same influence at work in the development of what has almost become a tradition or style.

No record would be complete without some reference to the Anglican Cathedral at Liverpool

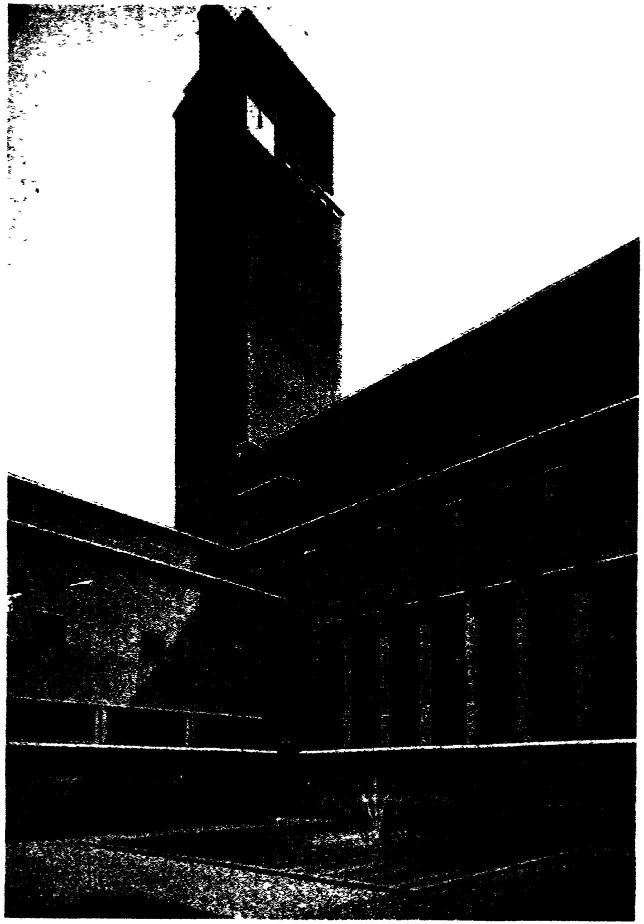


Fig. 154. Hilversum Town Hall

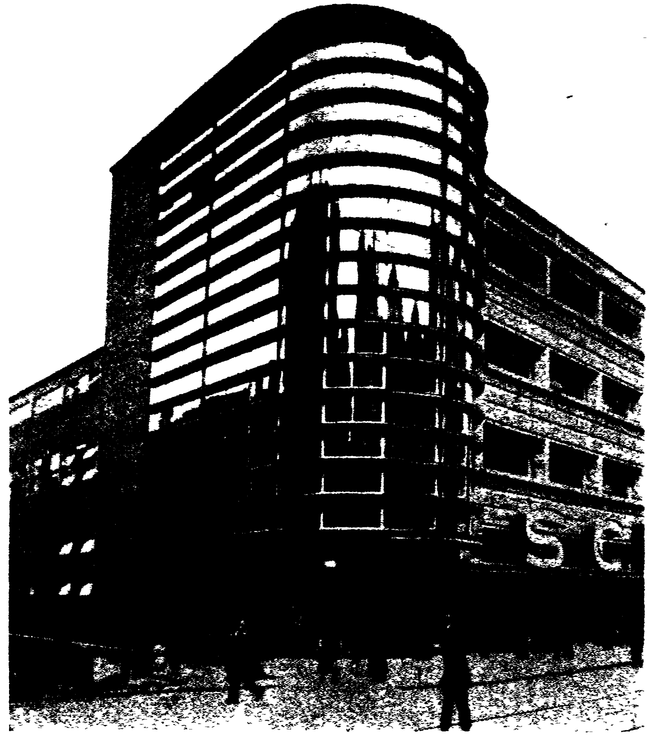


Fig. 155. The Shocken Store, Stuttgart

(Fig. 153), now nearly completed to the design of Sir Giles Gilbert Scott, R.A., and to the Roman Catholic Cathedral in the same city, designed by the late Sir Edwin Lutyens,

FIG. 156. THE EMPIRE STATE BUILDING, NEW YORK

R.A., but hardly commenced at the time of his death early in 1944. These two cathedrals, the former in the Gothic manner and the latter Classical will in due course stand as monuments to the skill and ability of two of the greatest architects of the twentieth century.

Architecture Abroad. It is not possible in this brief history to refer in detail to modern architecture in other countries. In Northern Europe, classical form and details have been maintained, but used with considerable skill and regard for contemporary methods of construction and materials. In Holland the use of brickwork has been developed, sometimes with a very eccentric detail, but usually showing an attempt to evolve an architecture that is the simple expression of an extremely functional method of planning. Fig. 154 illustrates one example in which the design owes nothing to tradition, but is the logical outcome of the skilful adjustment of massing in relation to the plan.

In Germany may be found some of the most advanced ideas, in which tradition has been more or less completely abandoned. An advanced and sometimes ingenious form of construction provides the basis of the design, and usually there is a conscientious attempt to provide a well-reasoned solution to the building problem, but at times there is an element of theatrical display that cannot be supported by reason of economy, construction, or utility. A characteristic example is illustrated in Fig. 155.

In America, architecture has been developed on essentially national lines. The skyscraper is in many respects an economic necessity, but it appears also to have become a national institution, and the tall building is perhaps the most characteristic feature of American architecture of to-day. It is very interesting to trace the development of the tall building from the early examples in which façades were decorated in the manner of the Italian Renaissance, through a transitional stage in which inspiration was more appropriately taken from Gothic examples, up to the present day, when buildings appear to take little serious account of historical precedent, and are modelled so as to produce a fine silhouette.

The architecture of America does not always provide the same valuable source of study for the student as does the architecture of Europe, but it should always be viewed as an excellent example of the adjustment of architectural development to meet the needs of contemporary scientific and economic conditions.

Fig. 156 shows the tallest building in the world, the Empire State Building, New York.

Architectural Review

MAISONS LAFITTE, THE CHATEAU
From a Water colour by Cyril Farey

Architectural Drawing

By WALTER M. KEESEY, M.C., A.R.I.B.A., A.R.C.A.
with contributions by F. E. GREEN, A.R.I.B.A.

Chapter I—EQUIPMENT AND PRELIMINARY WORK

THE training of the architectural draughtsman has received very considerable attention of recent years, and the impetus given to it by the growth of the large architectural schools and the establishment of new centres all over the country has been very marked. Formerly, draughtsmanship was mainly dependent on the carefully executed drawings which came from the chief architect's hands, and which received the flattery of imitation by the younger men. Fortunately, architects have, generally speaking, always been excellent draughtsmen of the "essentials" of their work, but the expense of reproduction was a considerable hindrance to freedom in method, and consequently the ink line drawing was most generally used. Another factor was the contemporary simplicity of construction, which needed but few differences of representation; brick, stone, and wood being the chief items, with occasional steel girders appearing only on the sections.

The new age of concrete and steel has, however, acted as a tonic upon the requirements of architectural draughtsmanship, and a new series of clean cut, decisive, and easily read methods of representation has been evolved. This evolution has been gradual, of course, but a comparison of an average set of plans of 1900 with those of the present day would reveal many salutary changes both in formal expression and artistic treatment. The progress of reproduction generally, but particularly in " true-to-scale " prints and pencil reproductions, has affected the standard considerably; both methods show how the minds of the various well-known men work at all the stages before the final "inking in," and that some of the personality of the original designer is inevitably lost.

It will be recognized, then, that architectural draughtsmanship is something more than a mere recording of facts on paper; it can be made to display a personality of treatment, which, apart from being intriguing, can, and usually does, express all the varieties of thought and well-considered design which the architect desires to convey to the actual constructor.

This is very evident in a highly decorative scheme containing sculptured forms, when the drawings compare very remarkably with the finished building. A notable case in point would be, for example, the Central Hall, Westminster, designed by Lanchester and Rickards, and bearing on its stone surface an unmistakable likeness to the actual drawings, even after passing through the hands of the builder and sculptor. Such fluidity of thought and pencil must be the envy of most architects, but the present-day training endeavours to compete with the problem with a very great measure of success.

One is inclined to believe that the decorative work in such an architectural scheme as that of Maison Lafitte, shown in our frontispiece, must be due to the ability of the architect and the sculptor combined. It is generally understood that in a broad way the architect decided what was to be the position and general type of decoration, and that the sculptor carved his own interpretation of these plans. Most old work gives the impression of personal character in the various treatments of stone, wood, or plaster, and such study as can be given to decorative work is amply repaid by the observation of these characteristics.

This water-colour drawing by Mr. Cyril Farey is an excellent example of his methods of work and should be referred to during the later lessons on " Rendering." Note the simplicity of the washes and the concentration on certain parts of the scheme of colour.

Basis of Draughtsmanship. What, then, is to be the basis of study ? A capacity and inclination for drawing is obvious ; and drawing, from the point of view of an architect, can only be considered as a means to one end, and that end is *expression*. The chief means of expression on paper is *line*, and this may be considerably amplified by the use of *tone*, either in light and shade, or *colour*. The student, in this

purely technical side of his training, is faced with the problem of the expression of the surface and volume of objects both in plan and elevation.

Surface we know to be the result of the composition of many underlying elements, and a knowledge of these is essential before positive expression can be described or illustrated. No two surfaces of different material, or two surfaces of the same material on different planes, or under different conditions of light and shade, should be drawn in an exactly similar manner. The powers of the draughtsman must therefore be infinitely varied and flexible, and in addition they must be directed and controlled by his capacity to visualize or imagine an object under the conditions which affect its representation in a drawing.

These various factors make it almost impossible to standardize any type or manner of line or tone in draughtsmanship; stronger outlines or accentuated detail are suitable only for the simplest surfaces and planes. At an early stage most students realize the importance of an ability to express general planes, both in plan and elevation, but such artistic facility is not easy to acquire.

The methods by which the teaching of architectural draughtsmanship may be approached are probably as varied as are the personalities of the teachers; but a brief outline of routine work is suggested, which, in lieu of the extensive training of a modern school, might be entered upon with little previous experience. Individual labour is invariably hard, and knowledge can be acquired only by the constant study of contemporary work. All types of work become grist to the student's mill. The syllabuses of the various schools make illuminating reading, and consultation with the bibliography given would explain very quickly the reasons for the methods adopted. For the benefit of the novice, the progressive stages are summarized, while in later chapters the particular subjects are amplified.

Suggested Course. It is impossible to divorce architectural draughtsmanship from architectural education; the suggested experimental work has, therefore, a twofold purpose—a training in the artistic and architectural appreciation of the objects studied, and also a training in facility of draughtsmanship, which is essential to representation.

The more easily and readily this is achieved the more quickly is the brain enabled to think, the eye to perceive, and the hand to obey and produce on paper.

A good general education is essential; too much stress cannot be laid on this. It may also be pointed out that a bias towards a future occupation could easily be arranged during the last years of general school education. Geometry and mathematics are essential, and historical architectural reading a great advantage. Freedom in drawing, particularly analytical, should be cultivated, and the memory faculty trained to the highest degree.

The further subjects of study should include geometrical pattern, solid geometry and projection, use of scales and general precision, model drawing and perspective, museum work of all sorts, lettering, measured drawings in various materials, constructional drawings and requirements, sciography or shadows, rendering in tone and colour, holiday sketching, competition drawings, and finally, working drawings for the job. It will be readily understood that as the above necessarily omits all reference to the more technical branches of the profession—such as architectural design, planning and construction, materials and hygiene, colour decoration, and professional practice—the province of the architectural draughtsman becomes a very wide one. He should be acquainted with the general importance and suitability of all decorative features, fittings, and details; he should have a reasonable knowledge of the various periods and styles of decoration and furnishing; and he should have a vast amount of common sense and imagination in the application to the job of the moment.

Equipment

The following suggestions must be accepted as applicable only to normal periods of supply. Reference should be made to current catalogues.

Boards. The student's outfit begins with the provision of board and T-square, instruments and set-squares, scales and 2 ft. rule. The average student would need a half-imperial board and T-square, full imperial board and T-square with ebony edge.

These two boards are small enough to make battens unnecessary, but an ebony-edged and battened double elephant board should be acquired later. It may be convenient to explain the various terms and sizes used in the profession: Imperial = 30 in. × 22 in., half imperial = 22 in. × 15 in., double elephant = 40 in. × 27 in., and antiquarian 54 in. × 32 in. These

dimensions agree with the standard sizes of paper. The half imperial board and T-square are most useful for general measuring and museum work. Get a good T-square and board while you are about it. If by any chance a T-square is damaged, but still has a fair edge, keep it for a straight-edge and for cutting purposes. Never put a knife to the true edge, always cut against the lower side, and with the square on its back.

Set-squares. Celluloid set-squares are most generally useful, and give an opportunity to watch the work covered, while those with a bevelled edge are most useful for inking in. A scale or other similar flat article should always be placed under the tip of the square, to prevent any flooding of the ink to the paper. Always look at your pen's inside surface when putting to celluloid, as this material seems to attract ink almost as much as it attracts fire. The 45° and 60° types, with 6 in. to 9 in. edges, are most satisfactory for the beginner. Variable set-squares are also very useful for setting to occasional angles.

Drawing Instruments. These are particularly a matter of taste and expense, but it is a wise economy to buy a good set in the beginning. The double-hinged type are preferable, and some people prefer to buy good single instruments, putting them at once into a spare box where other things, such as pencils, pens, etc., are kept, rather than to pay a lot for an elaborate box with gold mounts and two or three trays. These "presentation" sets are usually excellent, but difficult to carry around in your pocket. A most useful article is the *rolled instrument case*, made of chamois leather, with compartments like a "housewife" needle set; this is portable and elastic and keeps the instruments always bright and clean. Bow compasses on account of their delicate size are usually best kept in their own small case. Proportional compasses are for later stages of studentship, as are also beam compasses. The former explain themselves and are extremely useful friends; the latter (for very large circles) are easily made for temporary purposes, with a lath or rod of suitable length and strong spring paper clips at each end to hold the pen, pencil or point. They are expensive luxuries for the average student, and seldom used except for full size details or setting out wide curves, such as are found in arches or Gothic tracery, etc.

Scales. The most useful scale for the desk is the boxwood 12 in. one, marked with $\frac{1}{8}$ in., $\frac{1}{4}$ in., $\frac{1}{2}$ in., 1 in. on one side, and $\frac{3}{8}$ in., $\frac{3}{4}$ in., $1\frac{1}{2}$ in., 3 in. on the reverse. Various paper scales for occasional jobs are available in a box, and can be obtained as required. A 6 in. scale (preferably ivory) should always be carried in the pocket and made into a friend, while a small folding ivory 12 in. scale is extremely valuable, and should be constantly and freely used in order to gain a knowledge of the comparative sizes of various rooms wherever one may be, as well as

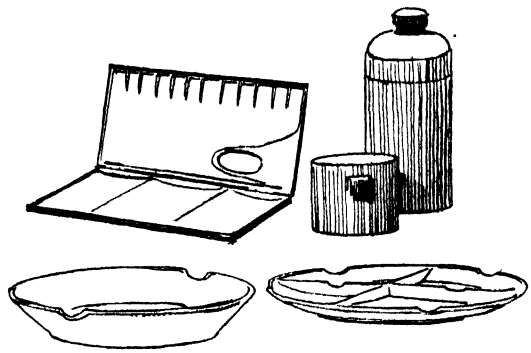


Fig 1. Student's Colouring Materials

such things as sizes of doors, gateways, roads and pavements, heights, overhang of cornices, etc.

The straight-edge has been mentioned already and is a most useful thing for perspective, but the 12 in. boxwood adjustable angle is an essential for reproducing all odd angles, pediments, buttresses, diagonals, projections, etc. And, lastly, perhaps the most permanent companion is the 5 ft. rod. A vast amount of intelligent measuring can be procured from the ground with the aid of a chair and a "five foot."

Water Colour Boxes, etc. A certain amount of equipment for water colours is essential. Primarily, the student wants colours and brushes, water-pot and saucers, but as it is assumed that he is anxious to improve his technique generally, a box suitable for sketching, and also for rendering, is advisable. The best type of box is the japanned folding palette, shown in Fig. 1, and a few colours selected for definite work (see list of colours advised). Half tubes can be readily replaced and are much better for general work than solid cakes or pans of colour. A water bottle of the flat variety is very useful.

Shading Pens. The pens illustrated in Fig. 2 are also a useful portion of the equipment. The steel nib marked 6 is one of many sizes, and can be purchased under the name of "pens for ornamental writing," complete with a "spring" to make a reservoir for ink, or colour. These

nibs are extremely useful for script writing and general details, as well as for blacking in walls, etc., and should be filled on the spring side from a brush, to prevent flooding.

The tin spring shown is easily made by cutting a strip from the top of a cigarette tin, and bending as shown to fit in the holder of an ordinary

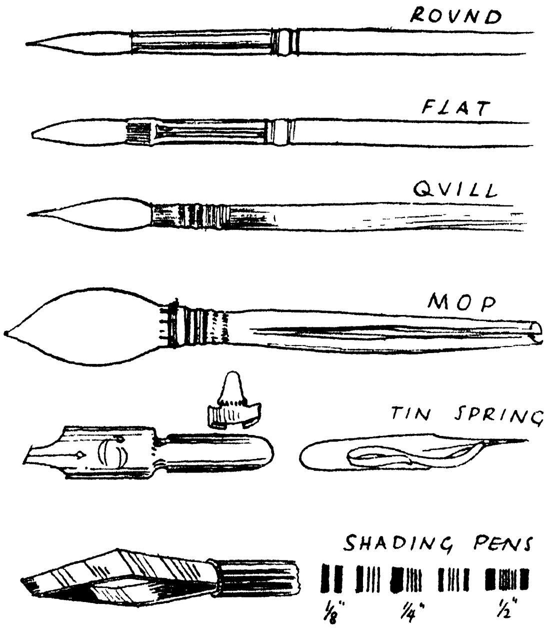


FIG. 2 SHADING PENS

pen. It is useful for the drawing of any line details when inking in, and flows much more readily and steadily than the ordinary pen nib.

The shading pens are obtained in many varieties, such as those illustrated, and, apart from their use for hatching in sections, are usually of great service for borders and frames to drawings. When making the angle, or mitre, of such frames, a piece of thin detail paper, with clean-cut edge, should be held across the mitre line and the pen drawn firmly over it along the T-square edge. Turn the T-square on its back to raise the bevelled edge, or keep it away from the paper surface by two scales placed underneath. These pens should be used full to dripping point, but with caution.

Brushes. It is an economy to purchase good brushes at the beginning, and the essential ones are—

Finest red sable, Nos. 2 and 6, round.
Sable wash brush, ¾ in.
Mop brush.

Take care of your brush; never leave it standing on its point in the jar. Clean after every fresh colour; do not squeeze the water out with your fingers, or the hairs may come with it. Rinse and flick out the water (under the table). If several are kept for any length of time, keep a rubber band round them, and put a handle to each brush for mutual protection.

China Ware. The nest of saucers is a good investment, but seven or eight ordinary saucers are very suitable; washes can be mixed in these, if necessary, but they should always be covered over at night. When mixing tube colour, always spread the colour on the edge of the saucer, and keep all similar colours together; for permanent work the basin palette is advisable.

Colours. The list of colours given below will be found adequate for all general purposes, certainly until the student has experimented and discovered the main points for and against each colour.

Yellows. Yellow ochre, raw sienna, burnt sienna, Chinese orange, chrome No. 1.

Reds. Light red and vermilion, Alazarin crimson.

Blues. Cobalt, French ultramarine.

Black. Ivory.

Greens. Viridian, Hooker's green, emerald green.

Browns. Raw umber, brown madder.

Chinese white is better bought as process white in the bottle. This is as cheap as, and stronger than, the tube, and dries dead white almost at once.

Some supplementary colours for later use are: Peach black, cerulean blue, brown pink, warm sepia. These colours are very beautiful in themselves, but need care in use, particularly when they are mixed with other and more earthy colours. This is explained more fully in the chapter on "Rendering."

Never use crimson lake or Prussian blue at this stage. They are both strong stains and cannot be washed out.

A sponge and blotting paper should complete the outfit.

Care of Materials. A word must be added in favour of clean habits, clean boards, and clean materials. As soon as a subject is finished all instruments should be cleaned; petrol is useful for mahogany, and slightly soapy water for set-squares. All paper should be stripped from boards. If the remnant edges of strained paper still refuse to come away from the board, a good plan is to fold up strips of newspaper (like an

enlarged spill) about 3 in. wide, soak them thoroughly, and lay them over the remnants for some time. These will moisten the paper and paste from the top, and it will very soon come away freely, allowing the paste to be sponged off easily. Do *not* immerse the board in water, nor wet it more than you can help. The best way to spoil a good board is to put it under the tap, leave to dry in front of the pipes—and forget it. You will find on your return a perfectly good wreck.

It is as well to look ahead a little to the time when, carefree and full of traveller's joy, you pack up for a measured sketching holiday. A good satchel can easily be made or bought which will contain a half imperial board and assortment of paper in one pocket, while the other holds, perhaps, instrument roll, scales, colour box, water bottle, and camera, while the T-square can be fitted to the outside in a special flap, together with 5 ft. rod and sketching stool. Do not cut up paper into small pieces until required, and always keep a stiff three-ply board to protect the paper while in the bag, and to act as a sketching board. A hole in each corner, and a string to go around the neck, saves a great deal of strain in holding, and also leaves the hands free for colour mixing or use of instruments. Some small eyelet hooks for the board serve the same purpose, and can be taken out when not needed. Incidentally, do not always put pins into the corners of drawing boards; it ruins them in time and any part of the paper edge is equally efficient.

Paper. There is such a very wide range of choice in the matter of paper that only the few which have been tried and proved by experience are suggested. The main point is, of course, to choose a paper specially for the job in hand. Blotting paper is obviously useless for water-colour work, and good paper is too valuable to spoil for the want of a little thought.

Cartridge paper is machine made, and the most common in use for all temporary purposes. There are some twenty to thirty defined qualities in cartridge papers; very cheap paper is of little service to the draughtsman, but some of the higher grades are very pleasant to work upon. Cartridge paper has two surfaces (most machine papers are the same), and if inspected one side will be found to contain a mark similar to linen, which is in fact the outcome of being the surface next the rollers in the manufacture, and should not be chosen for the surface to work upon. Continuous cartridge is very tough and good, and makes excellent detail or F.S. (full size) paper, while being extremely fine for some large washes of colour.

Whatman is the widest known hand-made paper, and is very trustworthy; the 90 lb. is good, but the 120 lb. to 140 lb. extra thick is lovely paper to work upon for colour or rendering. The water mark should be watched. There are three main varieties of surfaces: *H.P.* (hot pressed), *Not* (not pressed), and *Rough.* Rough is for loose, open-work, colour effects principally, and has much too coarse a grain for general architectural work in pencil. The H.P. is, as its name implies, pressed or ironed hot to form a "cream laid" surface, closing up the pores, and usually refusing colour. It is intended for clean pencil or pen line work, and colour should not be expected to run well on its shining surface. If colour is proposed as part of the finished work, it is well to choose a "not" surface for the sake of the colour and a harder pencil than otherwise might have been employed. Various types of paper are on the market, and should be experimented with by the student until personal experience becomes an efficient guide. Varieties worthy of trial are: Arnold, similar to Whatman; Michallet, a thin grained paper in various tints, very fine for line and tint or for crayon or charcoal, cheap and very reliable; Creswick, a heavy water-colour paper, slightly toned with a variety of surfaces; David Cox, a queer "home spun" type of paper, slightly tinted and with slight absorbent quality—very good for direct work, but difficult to handle when in trouble. Other papers are Varley, Van Gelder, Canson, Joynson, etc.

TRACING PAPER. This is the most useful stuff in the office, and should be used freely whenever another solution to the problem in hand is possible. It can be obtained in a variety of sizes and makes, but the one-third rolls (one roll divided between three students) are very useful and more economical than tearing up large sheets, besides being more handy for the satchel and pocket. Tracing paper is cheap when used in this way, and a constant repetition of an attempt to solve a problem on sheet after sheet is most healthy for the *morale*, and saves many a reputation.

DETAIL PAPER. This paper is slightly transparent but more permanent than tracing paper; it is made in large continuous rolls, and is most suitable for F.S. details or mouldings to a large scale. It takes a little colour if used with care, and is very good paper for decorative work or life drawing, etc.

TRACING LINEN. Tracing linen is for permanent tracings, and being its own negative is particularly suitable for the reproduction of contract drawings or photo printing. It is rather greasy to work upon, and should be well rubbed over with French chalk or "pumice" on the linen side before tracing. The glazed surface is usually coloured, if necessary, for details of materials, etc. A list of recognized colours is given elsewhere for this practical purpose, and colour may be applied more easily with the addition to the colour of a little oxgall (or even soap) to overcome the glaze. Many offices hang up several large sheets of tracing linen by one edge for a week or so in order to take out its "curl." This is better than rolling back, as is often done with ordinary paper, because the linen is liable to crack. Other papers can be obtained mounted on linen, and office practice generally is to work up the design to an almost finished stage on tracing paper or cloth, and have this printed on any desired paper for further work or colour, and, of course, for the reference file. Erasures should be most carefully done on tracing for prints, because any marks will, of course, reproduce unless specially treated, and the motto for such work must be "slow but sure."

MOUNTING PAPER. While on the subject of paper, a few hints might be advisable on straining the paper to the board. When a wash is applied to the centre of any paper that part will expand and "cockle."

The best way to mount a sheet of paper is always one's own way. However, some few hints might be useful. The object of mounting paper is to "stretch, strain, and straighten," if the slogan may be allowed. The writer will first give his own method for ordinary purposes, and explain other points later. Take a piece of *Whatman* (not-pressed) paper. Place the paper, with water mark down, on the clean board or a sheet of clean newspaper. Damp with sponge from centre, Union Jack fashion, until *all* the surface is wet, but not soaking. Allow this water to stretch the paper and damp again in five minutes' time, after you have prepared and cleaned the other materials. When the paper is thoroughly stretched, and all the shine has just gone, reverse it on the board loosely, without pulling. Square to a datum line, if the paper is already drawn upon, by moving the whole paper, and not by pulling one corner only. Now take a straight-edge or use the *back* of your T-square and place it half an inch from one of the longer edges. Hold the straight-edge firmly by the left hand, turn up paper edge with the right, and paste firmly, forcing the paste into both board and paper and pressing paper down with thumb—*without moving* the straight-edge. Now do the opposite side in a similar way, then one end, and then the other. When all the four sides are completed, do not pull at the edges (which being sodden will tear easily), but go over them again in the same order, holding down straight-edge and pressing the pasted strip with a bone-handle or other suitable round-ended tool; repeat this at intervals until you are certain that the paper is sticking evenly. The bone-handle gives much more pressure than the thumb, and you will find it will run easily after the first experience. Use some good paste, e.g. Higgins's Drawing Board Paste or Johnson's Mountant. Remember that water added to paste weakens it, therefore keep paper and board free from actual shiny wet. Work quickly. Watch the paper. If the straight-edge is used, the amount of paste is limited to definite margins, which can be cut off at completion of sheet.

The more colour or wash needed in the scheme, the more should the paper be strained, and the stronger the paper to allow of such straining.

All types of paper may be strained in this way, care being given to the treatment during sponging; slightly sponging the working surface of Whatman, or any tough-grained paper, enables beautiful washes to be laid with ease.

Keep all stains or colours off your board, and do not risk spoiling a good sheet of paper by careless handling. Soak off all waste strips and clean the board after use, ready for the next job.

It is most essential for good rendering to preserve the surface of the paper. Dirt and grease easily settle on the paper from the friction of T-square and set-squares, and water hates grease and will not stay on it. Protect your paper at both ends by strips of thick paper on which the square may slide, and keep all surfaces covered with tracing paper until actually needed. Erasures should be just as few as possible, particularly with the ink eraser; use a soft hat brush, if possible, to dust away rubber crumbs; most hands in the drawing office get greasy!

Rubbing Down. Rubbing down is a method of great service for duplicate sides of a scheme, whether elevation or plan. It is not absolutely accurate, but sufficiently so for sketch schemes. By this method pencilling, etc., in the final sheet is practically eliminated. The final drawing is

made on strong tracing paper over the semi-final schemes. A strong line (HB) is used, with all the details reversed if not symmetrical, and the tracing is turned over and fitted to the datum line (pencil down). Fix the paper with pins at frequent intervals, pinning through solid walls or shadows where practicable, and rub firmly

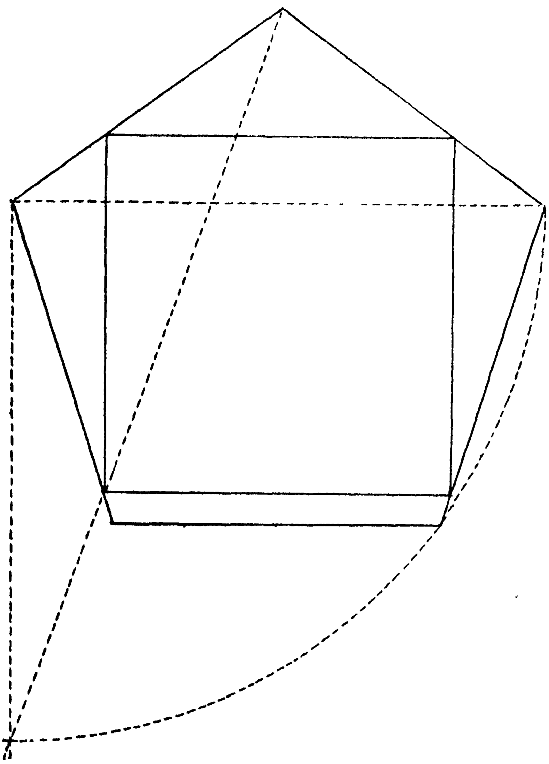


FIG. 3

on the back with a bone-handle or agate burnisher. Do a bit at a time completely, and do not scatter your rubbing. Use a piece of tracing linen to protect the paper if necessary. This method can be used particularly for repeat elevations or repeats of decorative detail, etc., and with care can be used two or three times in the latter case.

Preliminary Work

An understanding of the main principles of geometry and mathematics should form the basis of the training of every young draughtsman and every possible opportunity should be taken to gain experience and to apply such principles. Not only is this study a mental stimulus but it is also a marvellous opportunity to gain facility in handling drawing instruments and precision in constructing geometrical forms and patterns.

Geometrical Problems. A sound knowledge of plane geometry and of drawing to scale and from scale is essential for the student whether he desires to explain an important architectural scheme or only a humble roof truss. This subject is dealt with in other volumes, but the following examples will illustrate some typically useful problems which occur quite often in normal practice.

Fig. 3. *Within a regular pentagon describe a square.*

Fig. 4. *Given plan and elevation of an octagonal pyramid, to obtain projected sections.*

Fig. 5. *In a given equilateral triangle inscribe three equal circles, each touching two others and two sides of the triangle.*

Fig. 6. *Gothic geometrical tracery based on Problem 5.*

Fig. 7. *To inscribe seven equal circles within a circle.*

Fig. 8. *Construction of pattern taken from Moorish ornament.*

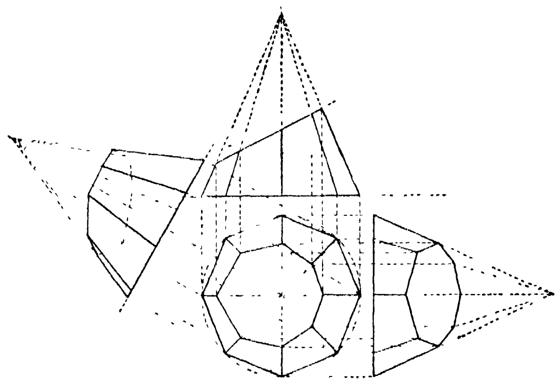


FIG. 4

Exercises such as these should be worked out with great care, and when sufficient precision has been obtained, inked in carefully with ruling pen and compasses. Contiguous circles offer many difficulties, and it is advisable to adjust the scale of thicknesses by trying the thin dotted lines first. Use ink which is well strained; if in bottles do not shake while in use. Apply the ink to the instrument by means of a pen or knife blade; a little and often is better than a full pen which may flood. Clean the pen frequently with a piece of hard thin paper and do not alter the adjustment more than necessary. Always bend compass points so that the points of needle and pen are perpendicular to the paper, otherwise the pen will scratch and wear unevenly

and the needle hole will be wide and ugly. The "patterns" are frequently most difficult to keep

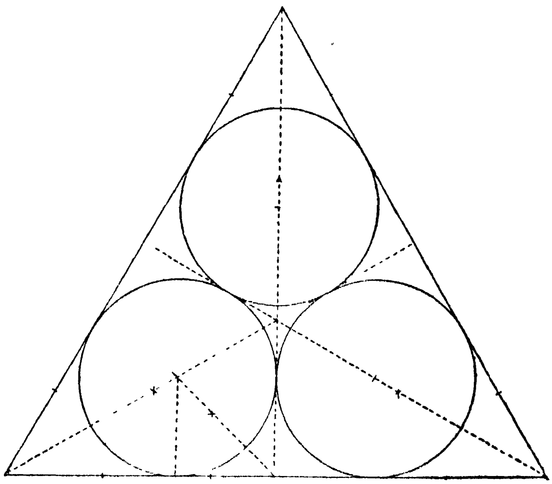


FIG. 5

quite consistent in width, and all main stems should be carefully gauged with spring dividers. Photos of Arabic geometrical tile patterns provide excellent examples for study; window tracery is equally interesting, apart from the fact that it provides a knowledge of stonework and jointing. Lines may be thickened according to their importance, and "inking in" generally should be practised whenever possible.

Geometrical Patterns. A great deal of instruction can be gained from the making of patterns; most architectural decoration has a geometrical basis, and many patterns can be made on a simple construction. Figs. 6 and 8 give samples of these types which, if used as a background for experiments in colour, become extremely interesting and informative. The colour box can be explored, and blending and harmonious arrangements made, which are sometimes very fascinating and technically of value in manipulation.

Scales. Before attempting any of these exercises, however, the student should master the use of the scale-rule; this is not difficult, and perhaps the easiest method is for him to make a drawing of some easily defined article such as a kitchen table.

If this table should measure, say, 3 ft. × 4 ft. × 2 ft. 6 in. high, he will make his drawing to a scale of 1 in. to 1 ft. and the table will appear as 3 in. × 4 in. × 2½ in. high, and so on.

A scale drawing is one which, when the object represented is actually too large (or too small) to be adequately shown on convenient paper, is reduced (or enlarged) to some defined ratio, e.g. ½, ¼, ⅛, $\frac{1}{16}$, etc. In all such regular cases, scales may be obtained already formed. The usual practice is $\frac{1}{16}$ for sketch or large schemes, ⅛ for general purposes, ¼ for small work, and ½ for detail; in every case here given the fraction is the part of an inch that represents 1 ft.; thus a ½ in. scale is a scale of ½″ = 1′ 0″ (1 tick = feet; 2 ticks = inch).

A ⅛ scale is large enough to show all general details and planning, but is not sufficiently accurate for scaling off dimensions which are usually figured on the drawings (see Museum Work under "Dimensions"). The scale of a drawing should always be drawn upon the paper, so that dimensions may be readily taken, even though the paper has shrunk or expanded with straining, or has been reproduced photographically. Numerous scales are on the market, but

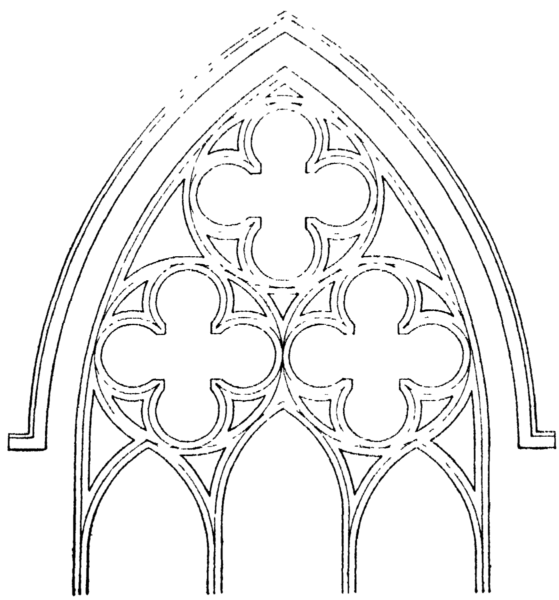


FIG. 6

for most practical purposes those showing ⅛″ and ¼″, ½″ and 1″, 1½″ and 3″, and ⅜″ and ¾″, on their respective sides are best. Paper scales are also obtainable in boxes of about twelve different sorts. They are more fragile, however, and rapidly get dirty, whereas a boxwood or ivory scale can be readily cleaned.

CONSTRUCTED SCALE. When the drawing has to be to an unusual scale, say, 2 in. to represent 5′ 0″, a scale must be constructed, and when once

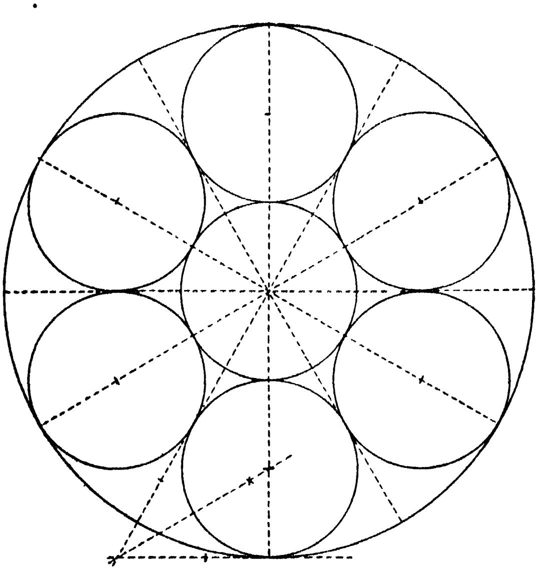


FIG. 7

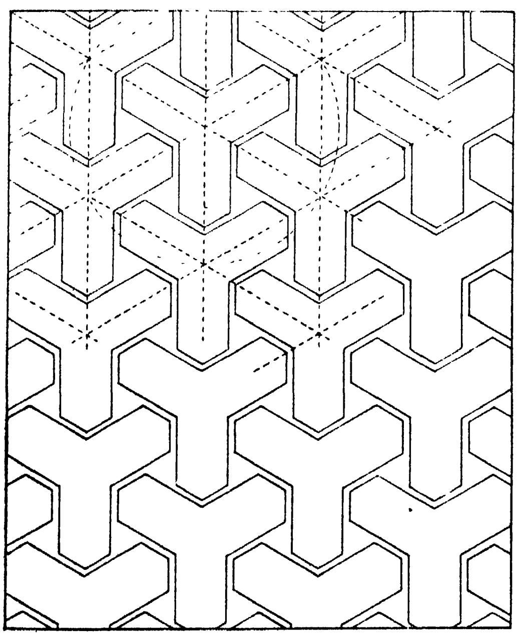


FIG. 8

made accurately should be transferred to a "tick strip" (odd strip of paper), and used in a similar way to the others.

To construct this type of scale, draw an indefinite line AB, Fig. 9, and mark off 2 in., as at AC.

Draw AK at any convenient angle and set out on it from A five equal parts to any convenient scale. Join K to C and draw lines from H, G, F, E parallel to KC, cutting AC. This will divide AC into five parts, and one

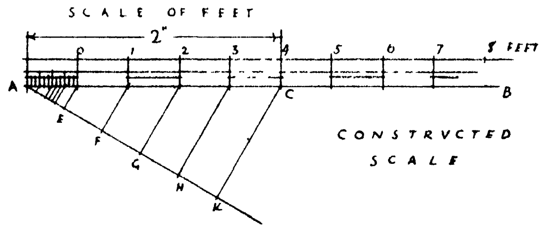


FIG. 9

part can be readily divided again into twelve parts for inches; produce the divisions as far along AB as may be desired.

DIAGONAL SCALE. These are most useful where the scale is small, such as in block plans, surveys, etc., or for minutely accurate dimensions. Let it be required to draw a diagonal scale of 2 in. to the chain, constructed to measure links, or

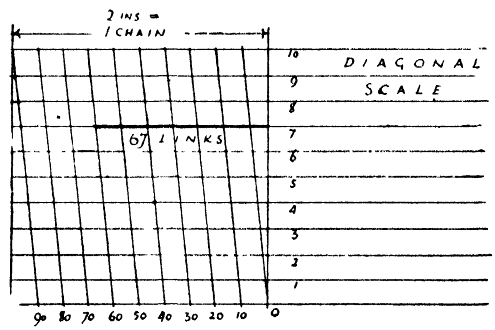


FIG. 10

one-hundredths of the chain. We must take two measurements, which will produce 100, e.g. 10 and 10. Divide the 2 in. line, Fig. 10, into ten parts as before described. Erect convenient perpendiculars from either side of 2 in. line and divide into ten equal divisions; through these divisions draw lines parallel to the 2 in. line. Join 90 to left top corner of rectangle and draw lines from other numbers parallel to it. Any measure of distance up to a 100 chains can now be obtained from the line agreeing with its last figure, e.g. 67 links could be measured on line 7, as shown by strong line.

Chapter II—CONSTRUCTIVE DRAWING

Projection. The student will notice, as he advances in his drawing, that it is necessary to show at least two views of an object before a clear representation may be obtained. Generally, one of these views is taken at right angles to the horizontal plane (as if seen from the front) and becomes an "elevation," while the other at right angles to some vertical plane (as if seen from above) becomes a "plan." For example, the part of a cube in contact with the ground is, of course, the plan, while the four vertical sides are elevations (N., S., E., W., etc.), and the top horizontal one might be termed the roof. These are difficult to show except in isolated drawings, but may be clearly expressed with the assistance of "isometric projection." In this method of representation all actually vertical lines are drawn vertically, whereas horizontal lines are projected at an angle of 30° to right or left, and measured to actual scale along each line. No "vanishing" is allowed for as in perspective, but while the method often distorts a large object, it is extremely useful in giving a three-dimensional view to a defined scale; it is particularly suitable for details of joints, penetrations, and other invisible details. When studying such forms, in connection with building construction details, the student should make a point of sketching the items in isometric, to gain added confidence both in knowledge and power to express himself easily.

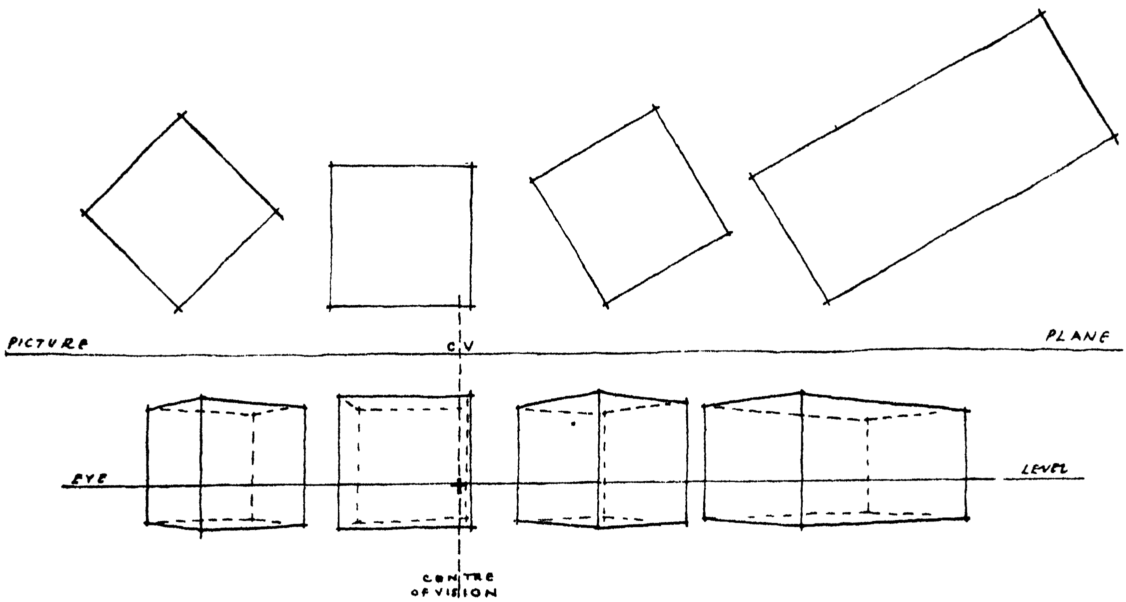


FIG II

Drawing from Models. When studying "projection," the student is recommended to experiment with the geometrical models. This is one of the best paths to that happy goal of all draughtsmen, sound expression, and can be studied better under the guidance of an art master at any School of Art than by individual study. Freedom is rapidly gained if the student realizes that parallel lines are parallel in isometric only for convenience. If one stands near a tunnel, and looks from one end towards the other end, the far end appears smaller than the near end, while all details, e.g. posters in a London "tube," will follow the general inclination to diminish with distance. Again, standing facing a pair of large doors (closed), the lines are at right angles with one another; open the doors

away from you and the lines now appear to vanish within the door opening. So soon, then, as one pushes a parallel plane away to right or left, the lines of that plane will *diminish* in equal relation. One cannot actually see the front of a cube (a perfect square) and, at the same time, see one of the sides. As soon as a side appears the front must be less square, as illustrated in Fig. 11.

A certain amount of similar thought pervades all the various forms, and one's judgment necessary for its appreciation is rapidly strengthened by exercise.

The reproduced photograph of the tower, shown in Fig. 12, is an excellent example of the type of form suitable for good instructive study; the diagram (Fig. 13) of the constructive lines explains itself, but particular attention should be paid to the various centre lines and directions of the elliptical shapes. Frequent drawing of circular shapes, at a fair height, will very rapidly teach the student the methods of drawing illustrated and explained in this chapter.

Study the diagrammatic skeleton lines of Fig. 13 and draw them over again through tracing paper. The base is cubical and presents the only difficulty of gauging the left side 1–2 with the right 1–3. Notice that all the horizontal lines would meet at some point on the eye level; also that the top horizontal square having been formed and the diagonal produced to the eye level, a vanishing point is made which is extremely useful for mitres of all similar angles. When the sides are nearly equal, as in this case, the other diagonal is nearly horizontal and the profile of these mouldings is more easily seen than in the foreshortened angles. Always check main width with main height overall.

The top circular tower is an interesting exercise in ellipses. Imagine it to be a plain cylinder subdivided horizontally as indicated in diagram; notice the gradually increasing height of the vertical axis *CD* and the permanent horizontal axis *AB*. This is important to note and must always be drawn; it is more evident in the diagram than in the photo, where other forms are liable to disturb its direction, but where it can be traced consistently in the large and the small details. The columns form a convenient guide to the disposition of the centres and should be drawn in before attempting the arcading. Their architraves become simplified box forms with their centre lines to the centre of tower. If the back ones could be seen they would obviously carry through from the front.

Another interesting and generally confused problem concerns the drawing of the vertical ellipse, as in the louvred windows. Imagine a large circular advertisement as on a street wall. Knowing it to be circular, you see it as a long

FIG. 12. CUPOLA, ALL-HALLOWS, LONDON WALL

thin ellipse when viewing from the same pavement close to the wall. Its greatest axis seems to tilt toward one direction, while its smallest axis seems to be in direct continuation of your "gaze." This really is so, and all vertical ellipses should be drawn (despite the perspective method, which is theoretical) as if the short axis were a line from your eye through the centre and the long axis at right angles to that line. Vertical ellipses will therefore apparently change their directions as the diagram indicates by the two *X–Y* and *W–Z*. A perspective "set up" for circles can only give their apparent position, after which the ellipses

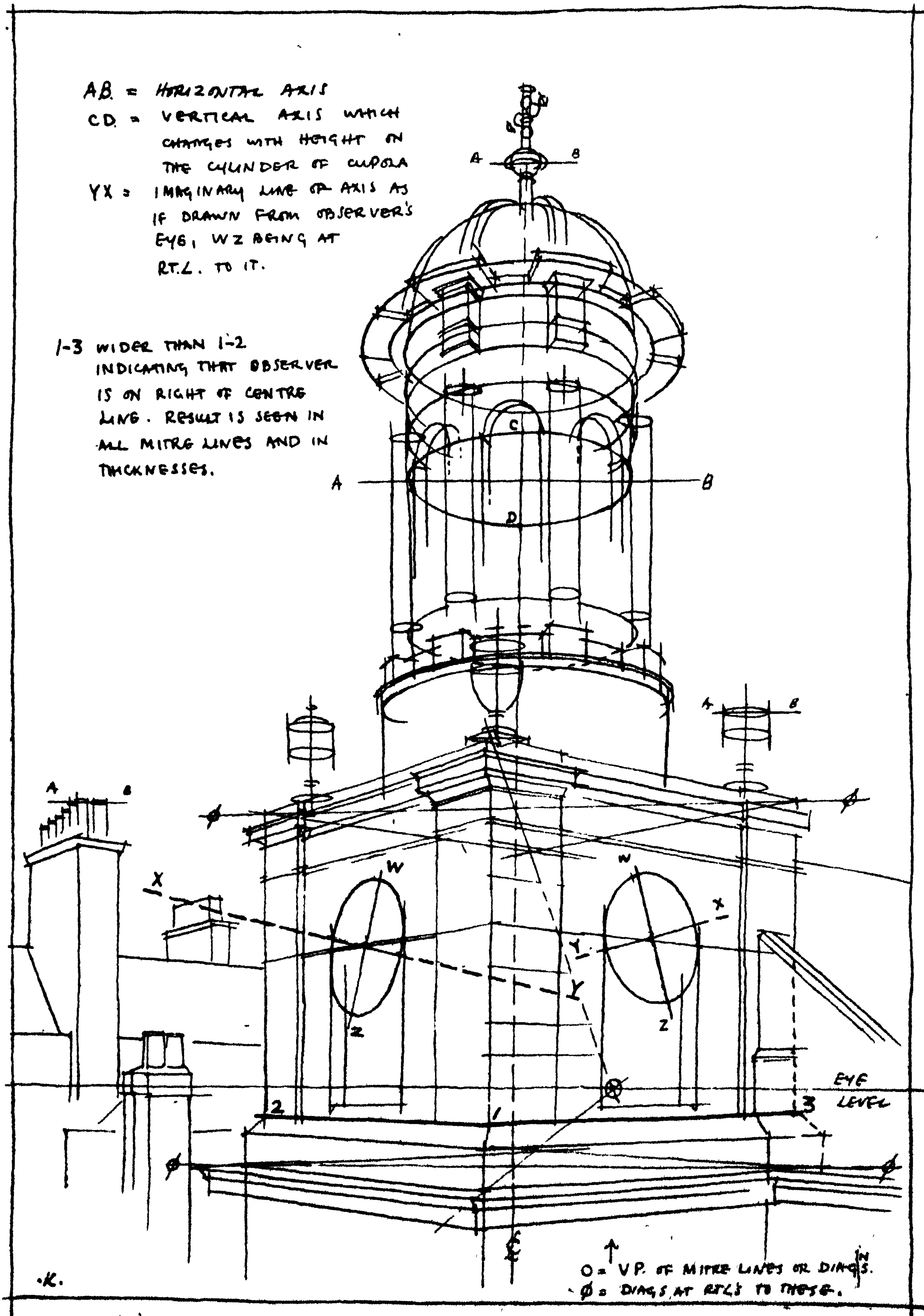

AB = HORIZONTAL AXIS
CD = VERTICAL AXIS WHICH CHANGES WITH HEIGHT ON THE CYLINDER OF CUPOLA
YX = IMAGINARY LINE OR AXIS AS IF DRAWN FROM OBSERVER'S EYE, WZ BEING AT RT.∠. TO IT.
1-3 WIDER THAN 1-2 INDICATING THAT OBSERVER IS ON RIGHT OF CENTRE LINE. RESULT IS SEEN IN ALL MITRE LINES AND IN THICKNESSES.
EYE LEVEL
O = V.P. OF MITRE LINES OR DIAGS.
Ø = DIAGS AT RT∠S TO THESE.
K.

Fig. 13

should be drawn in as above. When experimenting with this problem, commence with very distorted (side) views of clocks, arches, etc., or posters, as in the street already quoted.

Freehand Work. Many drawings should be made from models or similar forms, but it is a sad mistake to " line in " every exercise. This awful phrase really means, " Now I can give up thinking and just go over my lines ; in fact, I can turn my drawing upside down, and do it equally well or perhaps better ! " Get away from comfort and really study each line until perfection has been reached. Lines are used to convey an impression, and correct freedom in that impression is much better than meticulous care bestowed upon the lining up of a badly set up drawing. A good line arrives by constant alteration and consideration, until the hand obeys the eye as implicitly as does the eye the brain. It will arrive, however, more readily with the use of a soft (B) pencil for free drawing; fine work will not evolve if the pencil is coarsely sharpened or too small—or bitten at the end! Hexagonal pencils are good to learn to sharpen, and every facet should receive the knife first; after that every ridge, until a point about 1½ in. long (including wood and lead) is made. A long swinging stroke on a board, held at arm's length on the knees and towards the group or object, should be encouraged. Do not hold a pencil as you would a pen for this work; it becomes too limited in range. Give the lines a good "carry through" to gain precision and speed. For this reason, always make the drawing as large as is possible, and keep your eye on the shape outside as well as inside the group. A figure on a hill top against the light is easy to recognize, because the brain observes shape and is not distracted by detail; choose, then, simple "shapes" to begin with, and inquire into the construction of them afterwards.

Tone. Having drawn the group, assume the light comes from one direction, and try and cover the dark planes with tone. Put them in first with a brush, if you like, and a wash or washes of tone of different strengths. Later, use tracing paper and cover the same surfaces on another drawing with pencil, for the sake of the experience. If we take a square inch of paper and put lines ⅛ in. apart with a BB pencil a tone will result, i.e. eight lines to the inch; with sixteen a darker tone will be obtained, and so on. Also a harder pressure, or crossing the lines or adding dots, etc., will vary the tones. All these should be tried and, finally, when the tone is decided upon, put the selected tone in the drawing.

Some casts of simple strong shapes should now be tried out and the same principles applied. The casts which are so prevalent in schools of art are not there so much as samples of ornament as samples of shapes, and should be considered as such for our purposes. The *Egg and Dart* to a large scale is a most enlightening cast, and excellent for the study of tone and methods, being deeply modelled with contrary surfaces and strong shadows. Remember that, on such rounded forms, a shadow which is indicated with strokes like the lines of a bead curtain will surely hide all the shapes it covers instead of explaining them. Lastly, when drawing by means of shade and light, no actual outline is essential, and any preliminary lines should be considered only as guides to the surety of the final pencil lines. Heavy outlines only tend to destroy the surfaces within them.

Penwork. Practice with a pen at every opportunity. With a pencil the lines tend to merge, readily producing a tone; but with a pen all lines are distinct, and more courage and skill is needed to blend them. A pencil drawing can be "drawn into" without much trouble, but to fill in between pen lines is a very difficult matter. Use a pen, therefore, as a matter of course, and you will cease to feel frightened of it. Also use ordinary writing nibs (except, possibly, the " J " variety) instead of the deadly mapping pen, which, as its name implies, is made for a specially fine purpose. All sorts of nibs are on the market—some with two and three or more points—and should be tried out. If much work is expected, add a spring of tinfoil to the nib and transform it into a fountain pen. The flow will be much more controlled and the work more uniform.

Architectural Review

FIG. 14. DOORWAY FROM A HOUSE IN CAREY STREET, LONDON, EIGHTEENTH CENTURY

Chapter III—MUSEUM STUDY

An essential feature of the training of the architectural draughtsman is a good working knowledge of the construction and design of furniture together with internal decorative effects and fittings. Whenever it is possible, he should sketch, measure and plot direct on paper from the actual objects available in the museums of most towns. Apart from the decorative knowledge gained in this way, the actual need for being clear, concise, and analytical in such studies is the finest possible training. A great deal of general drawing is necessary, and the need for an ability to express different materials and effects gives wisdom which could otherwise only be arrived at under personal tuition at a school of art. This tuition is very desirable, but the supplementary training suggested can be practised at all times and rapidly tends to increase the initiative of the student. He should train himself at all times to analyse the essential factors of any work under consideration.

A comparative study of doors, windows, staircases, panelling, etc., at varying stages of their respective development will increase this critical faculty. The elementary methods of construction used in early work were usually fairly sensible, and well adapted to the tools at the workmen's disposal; except for the use of nails instead of pegs and moulding or jointing machinery, very little change can be discerned. The points to analyse most thoroughly are proportion, dimensions, joints, construction, and decoration. As a good exercise in this analysis, let us take a fine Georgian doorway, with its implied experience in measuring, plotting, construction, and draughtsmanship. The example given in Fig. 14 is a doorway in yellow deal (presumably painted), and is from Carey Street, London, W.C., early eighteenth century, now in the Victoria and Albert Museum, South Kensington.

Analysis. The main factor of a doorway is the door, and the first diagram made should be a small, clean, line sketch in our sketch book as shown in Fig. 15, giving the general proportions of the door with overall dimensions. Add the wall in which the door is held, if possible finding the thickness of the wall and the portion around the door—not always possible in museums. Measure these main factors and leave your first diagram as Fig. 15. Fig. 16 shows a further stage, including the architrave to door opening and general features of the surround.

Having found the main overall dimensions of the doorway to be, say, 13 ft. high by 8 ft. wide, we can decide that a scale of 1 in. to 1 ft. will allow for the plan and sections to be included on a half imperial paper, 22 in. by 15 in.; and a little thought having determined the position of centre lines, etc., we proceed to plot our measurements direct on to the sheet. This is most important, as it allows us to see how much we have forgotten to measure, and to emphasize the value of "through measurements." Our next sketch, Fig. 16, is on a new page of our sketch book, and gives further details of constructive detail, which we plot again, always plotting as the actual object is made and assembled, e.g. in the door itself the progress of drawing would be the lines as indicated by numbers 1, 2, 3, etc.

At this stage it is wise to make a F.S.D. of the various members, because it has to be done some time, and if done now can be taken away and plotted at leisure, whereas sketch book notes not to scale may easily omit vital measurements. Sections of mouldings are generally the same as side elevations, and should always include a small amount of the repeating decoration, if any, with centre lines of such repeats. Endless repetition of small detail is quite unnecessary for such study, and the example given is an excellent one in this respect. Do not omit the scale, and include any historical data available for future reference. Notice the joints shown in the door itself. Keep the lettering clear, simple, and legible, and the dimensions particularly obvious and straightforward. The finished and measured drawing is shown in Fig. 17.

This method is stated briefly, but it contains the pith of the system, and is the outcome of many years' teaching experience. It can be followed in the great majority of cases, and where two or more can work together much speed can be developed, one plotting while the other measures, etc.

A further stage that might be available would be such simple buildings as almshouses or a courtyard, where planning is almost more important than elevation. These cases must

be carefully studied, as frequently they are not by any means regular on plan. Diagonals should always be taken to check this. Squared paper is extremely useful for measuring large surfaces, as the sense of scale can be developed and proportions roughly estimated previous to actual measurement.

The value of study in the museum or from existing buildings and features, both old and new, cannot be emphasized too strongly. Mere imitation, however, of surface features is of little abiding value, and the real student will endeavour to train his mind not only to observe, but to analyse, and in analysing to memorize. Memory training is invaluable and highly consistent with the finest brains in the profession. I would quote from William James, who says of memory: "The secret of a good memory is the secret of joining diverse and multiple associations with every fact we wish to obtain; but this forming of associations with a fact—what is it but thinking about the fact as much as possible? Briefly, then, of two men with the same outward experiences, the one who *thinks over* his experiences most and weaves them into the most systematic relations with each other, will be the one with the best memory."

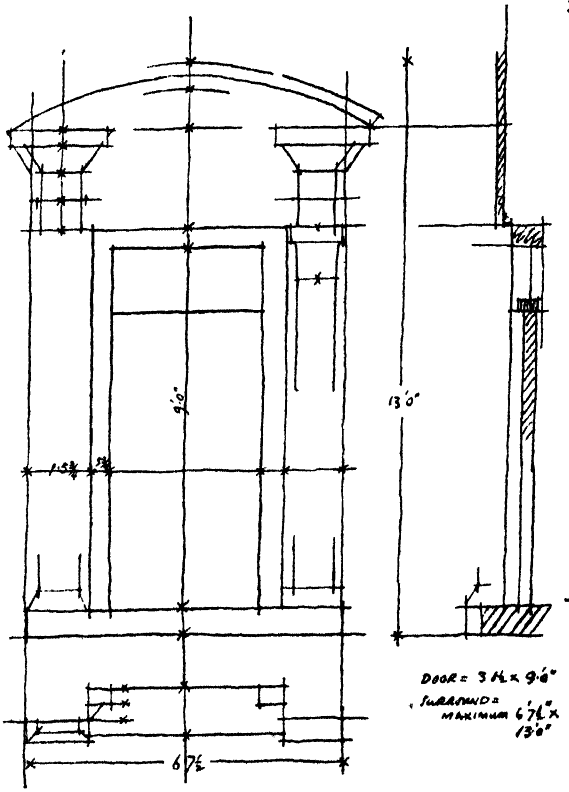


FIG. 15

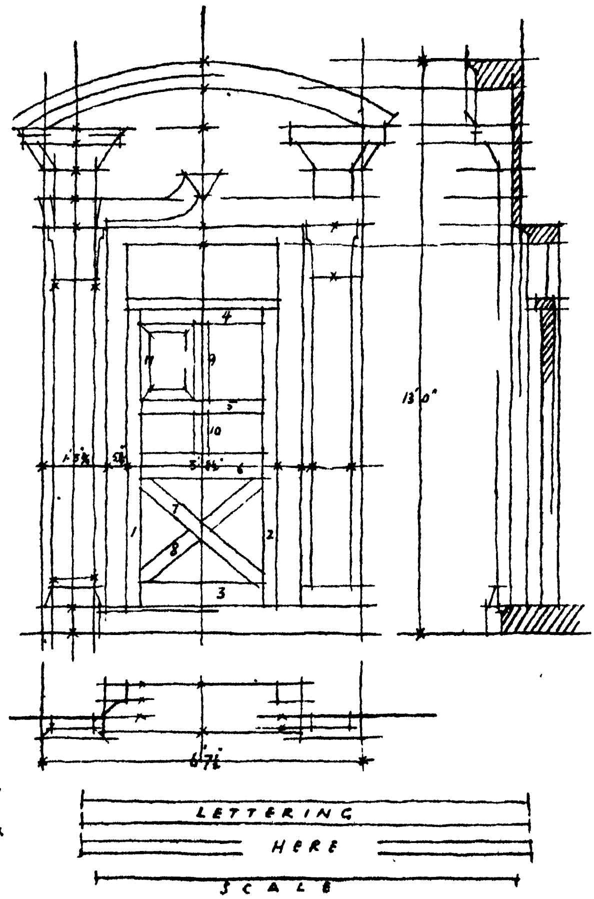


FIG. 16

Drawing from Memory. The habit of drawing from memory gives the student confidence to draw "out of his head," and must be of the utmost value to him as a designer; it forces him to think while he draws, which is far in advance of mere automatic imitation. At the same time, the drawing from objects is useful to the student, but these drawings should be of the most literal kind, in order to stimulate and encourage the analysis of the object and to record essential facts, rather than the mere imitation of photographic appearance. The final proof of the value of memory drawing is the help and assistance given to the designing power of the architect. Knowledge is power,

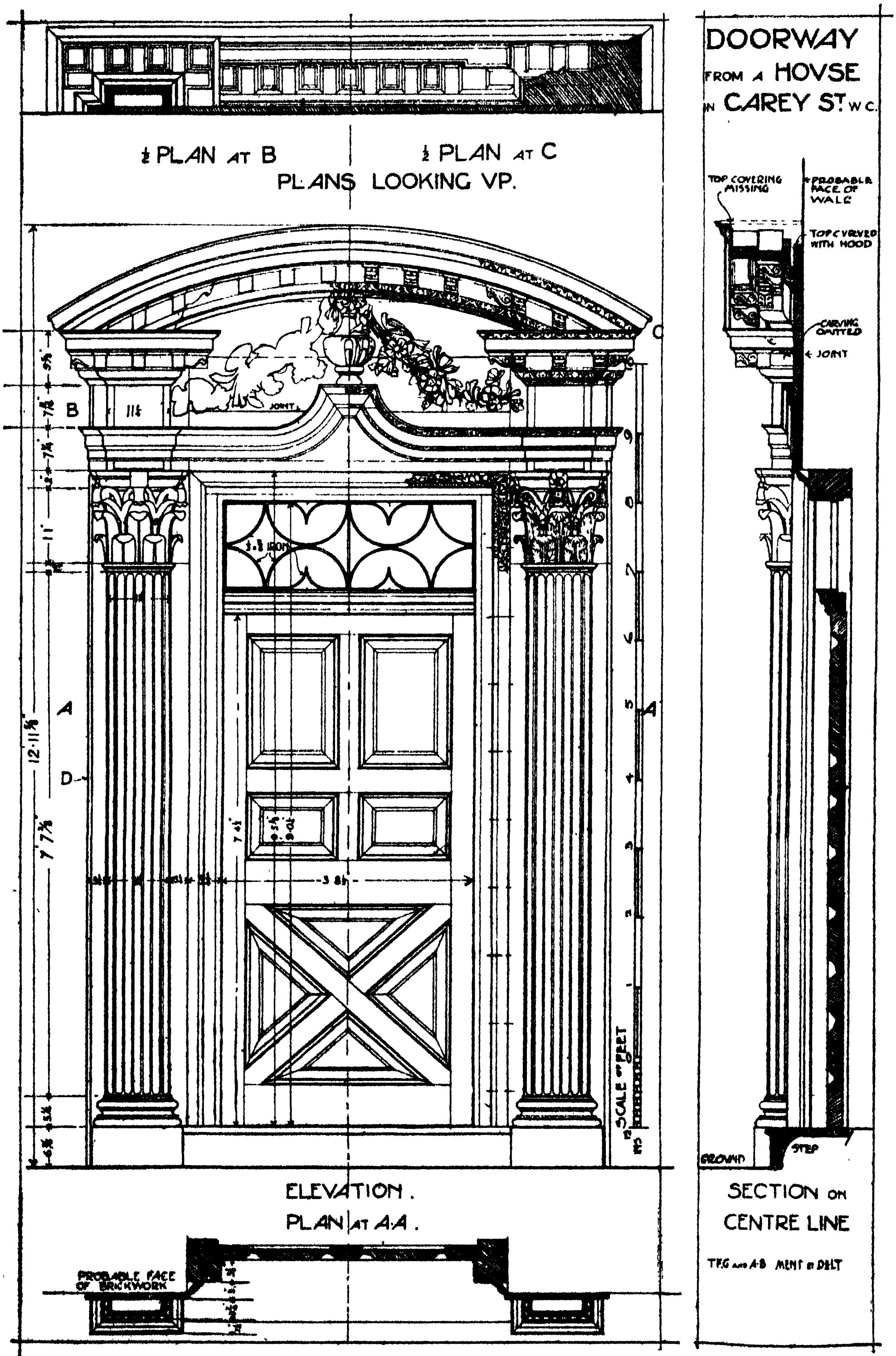

DOORWAY
FROM A HOVSE
IN CAREY ST. W.C.
½ PLAN AT B
½ PLAN AT C
PLANS LOOKING VP.
TOP COVERING MISSING
PROBABLE FACE OF WALL
TOP CURVED WITH HOOD
CARVING OMITTED
JOINT
B
A
D
12·11⅝
7·7⅞
3·8½
SCALE OF FEET
GROUND
STEP
ELEVATION.
PLAN AT A·A.
PROBABLE FACE OF BRICKWORK
SECTION ON
CENTRE LINE
T.F.G. AND A.B. MENT ET DELT

FIG. 17

particularly to the designer, and a broad outlook and retentive memory, combined with an analytical study of all the ancient and modern sources of information, must inevitably help him to keep abreast of the numerous waves of doubtful mannerisms and superficial "styles," which are so eagerly lapped up by the man of weaker mind.

Measured Drawings. Apart from the practical experience in constructional draughtsmanship gained by making measured drawings of architectural objects, it will be found that a good many details have to be carefully drawn with a line which must correspond with that already made by the instruments. This type of free-hand work is not as simple as it looks, and a great deal of practice is necessary before the two types of line may be said to blend together properly. Phil May, that master of expressive line, is said to have laboured at his "simple" drawings until the last inch of superfluous line had been expelled. The system of thought is much the same in all line drawing—"What can I omit without loss?"

Obviously, pure line draughtsmanship can only arrive after experience of a great deal of general work, and much practice. Drawing from life, whether human or animal, is most excellent practice, because the forms are somewhat strange to the eye, sometimes vague to the novice, and always demanding a line which is not only expressive but explanatory.

The architectural student must eventually endeavour to understand the outlook of the painter, the designer, and the sculptor; and for the cultivation of such understanding it is certain that the life model presents a maximum amount of inspiration towards freedom of line and beauty of composition. It has the added advantage, also, of teaching the student the external features of the living forms, and the importance of this is soon obvious to an observer of decorative features. From time immemorial, artists and craftsmen have used the figure for ornamental and decorative purposes, and it is rarely that one finds a decorated surface without such a motif; Figs. 18, 19, and 20, although representative of different phases of artistic production and materials, emphasize this fact very strongly.

Roman Life Studies (Fig. 18). "Roman life" studies, from the British Museum, are as yet crude in drawing, but the treatment has been intentionally forced around the section of the form in an endeavour to express it with the utmost rapidity; the tripod is particularly noticeable in this respect. Note that an outline is not really necessary, except where no other shading is possible or convenient. These drawings form an attempt to express the shape and the general quality of the material by expressive line work, or simple shading. The method is an obvious one, and if the form of the section is well explained its usefulness is served.

Renaissance Studies. Compare the foregoing vigorous designs with the delicately modelled Renaissance studies of Fig. 19. These drawings are a very great improvement in line. The form here has been realized intimately, and the line used to express it is amply sufficient for the purpose. This is the type of drawing which can be recommended for study, but it should never be attempted without due thought for the underlying masses. The small carved frame is very adequately explained, and sufficient information is included to revive the memory of the detail at any time. Notice the economical manner in which the detail, or repeating pattern, has been indicated, while sufficient measurements are included to enable the scale to be readily appreciated. When making personal notes of such dual-sided designs, it will be found that lightly squared paper is of great service; the scale can be judged very quickly, straight lines are easily drawn in, and, if one side is drawn carefully with a HB pencil, and the paper folded on the centre line, the repeating half can be rubbed over very quickly. This can be done for good careful work if one is content with a light rubbing to guide on main lines only. Always be careful not to crack the paper on the centre; put a T-square along the line and fold over it. Note, too, the carefully ordered method of indicating dimensions; they are sufficient for the purpose, but not too insistent.

Fig. 20, of an Italian fireplace, is another good example: a difficult form to measure and express, so that the method adopted of a comparative front and side elevation would seem to present most comprehensive treatment. Note the "fire-dogs" and the delicate treatment of the shading, only sufficient to indicate the roundness and texture of the object. This is an excellent type of drawing for the student—who, perhaps, is travelling and with little time to spare—presenting a careful analysis of the object, and measured in a straightforward manner with a view to its later service. Most of these objects illustrated are small in scale, but it must not be forgotten that when larger

objects are drawn, particular care must be given to the construction and manufacture of the object. Joints should always be indicated where possible, and the true craftsman would always endeavour to discern and indicate carved wood as from the solid block, marble

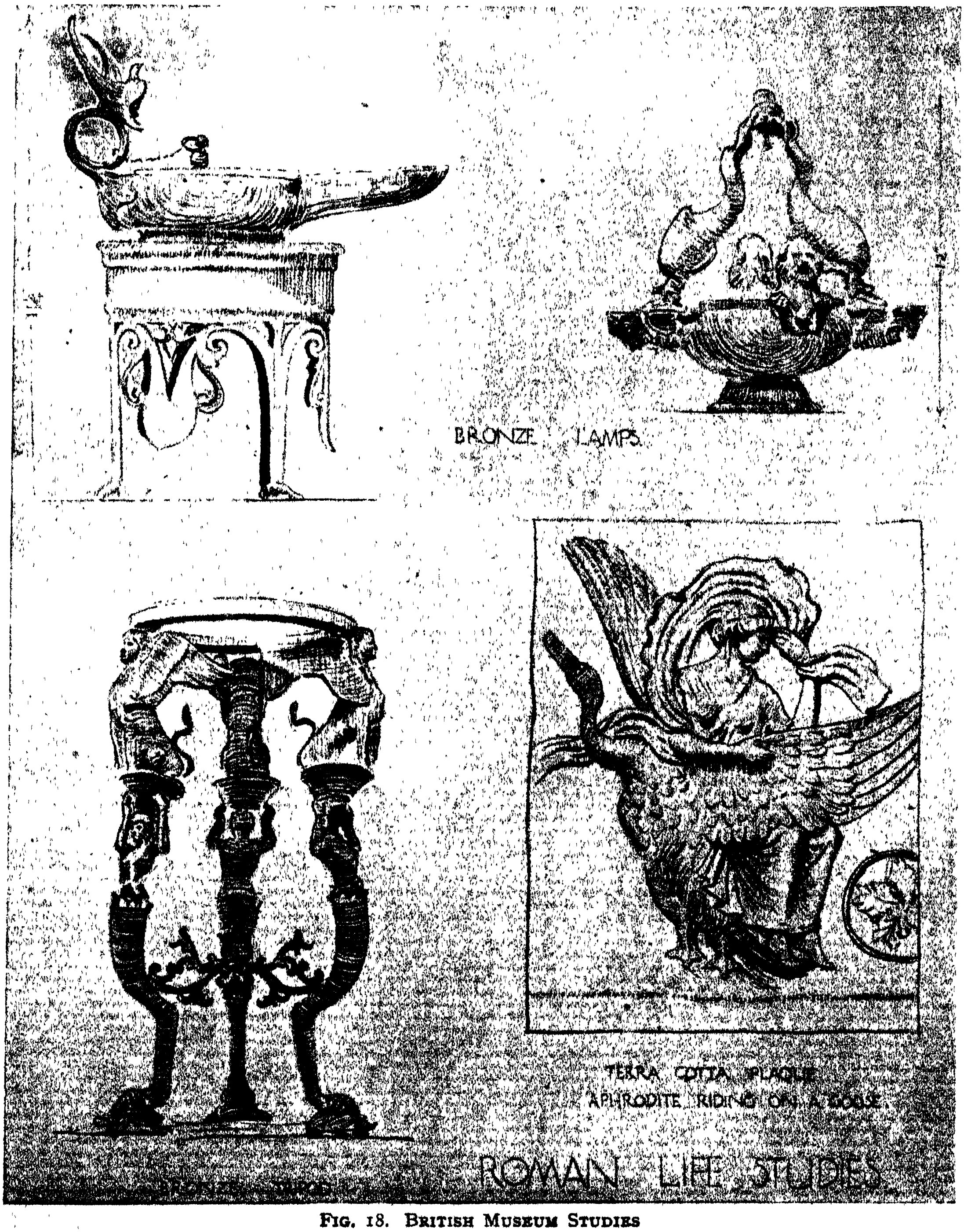


FIG. 18. BRITISH MUSEUM STUDIES

from the slab or piece, stone from the structural sizes, bronze from the consideration of casting, wrought iron from the strip, etc.; the most frequent cause of bad craftsmanship has always been the wrong use of material. For this reason, the materials should always be

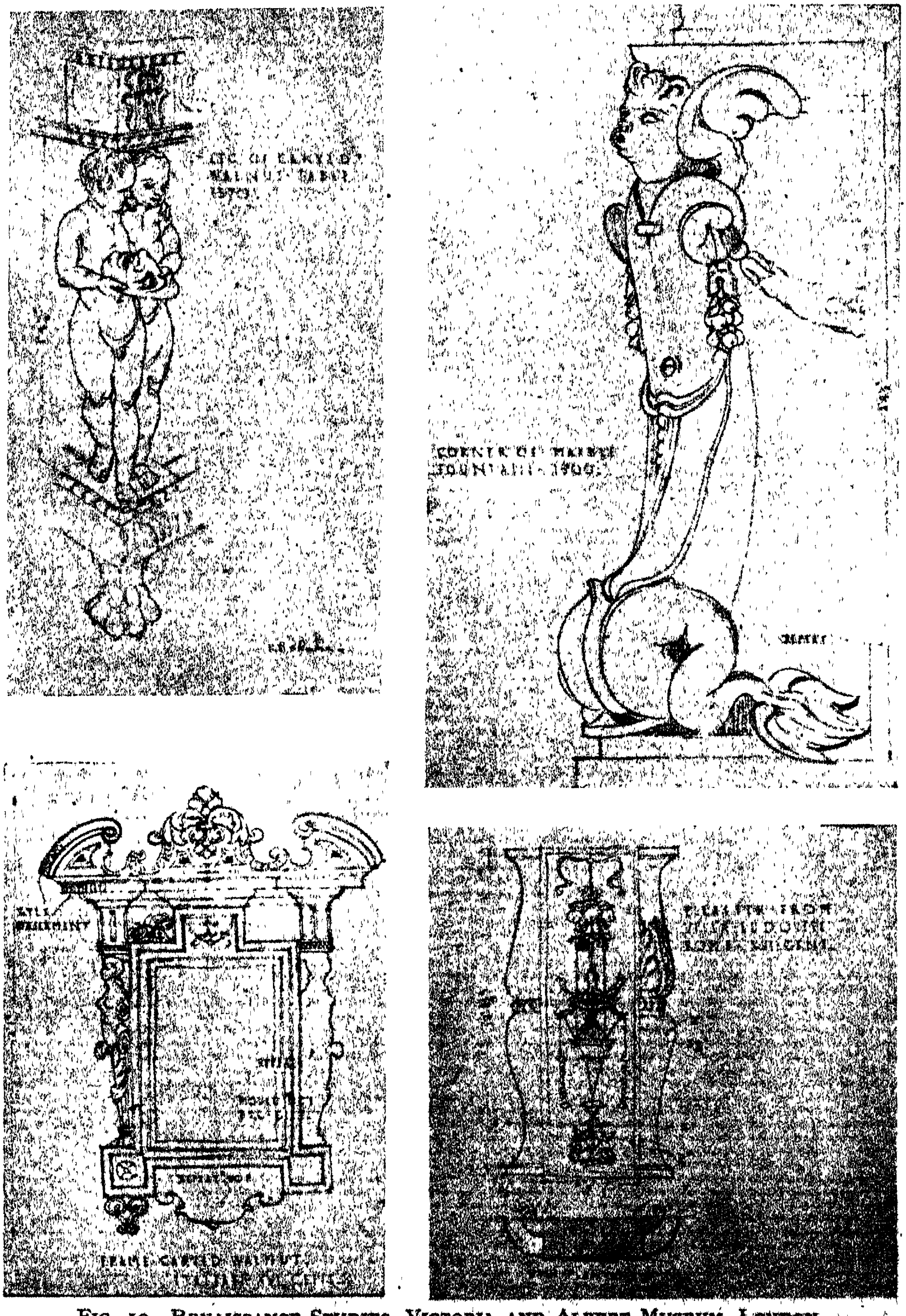


FIG. 19. RENAISSANCE STUDIES, VICTORIA AND ALBERT MUSEUM, LONDON

indicated; and if you cannot make your drawing look like it, include a note on materials with the other details. These examples are reproduced, with acknowledgments, from work in the Victoria and Albert Museum, London, by students of the Architectural Association.

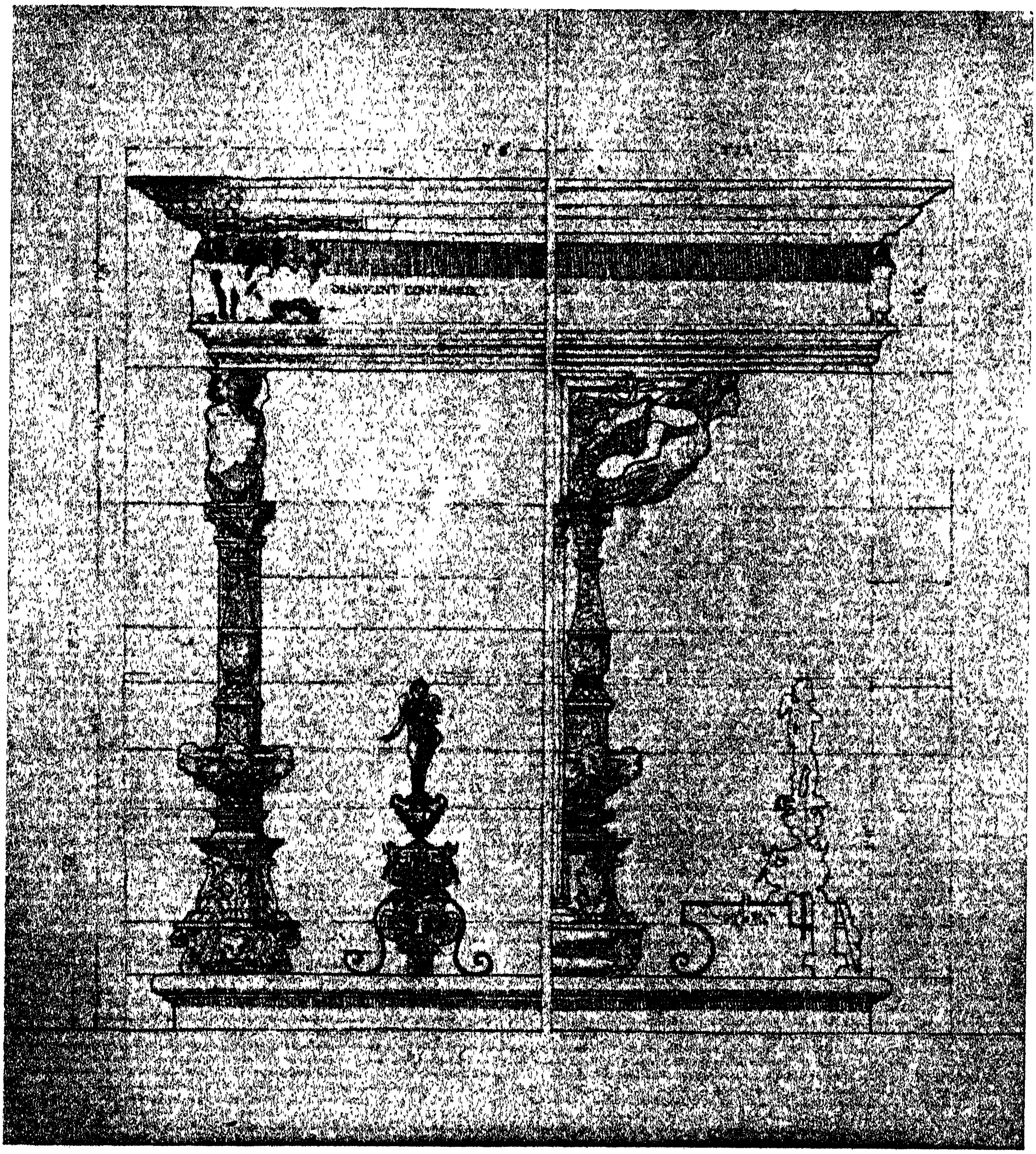


FIG. 20. ITALIAN FIREPLACE (RENAISSANCE), VICTORIA AND ALBERT MUSEUM, LONDON

Chapter IV—LETTERING

THIS subject should receive much more consideration than is usually given to it, for a sound and early appreciation of the form and construction of letters saves much labour in the later stages of the draughtsman's career. Many drawings are frequently ruined by poorly designed and weakly executed lettering. Such types as the Rustic letters (those sentimental letters made of sprouting logs) or the ultra Gothic forms (which were so highly decorated that they became almost unrecognizable) illustrate the great need for pure legible forms for everyday use. Fortunately, a revival of good letters is everywhere evident; started by William Morris and advanced by Edward Johnston in pre-war days, the work has been taken up by many schools of art, and is now spreading to the highest class of commercial house—perhaps the truest test and finest compliment possible. The Roman letter is the best for both legibility and decorative effect, and of this form perhaps the best example is the panel inscription in the base of the Column of Trajan, Fig. 21, a cast of which is in South Kensington Museum. A very fine panel of a similar nature has very recently been discovered in our own land at Wroxeter, and a good sample of Roman inscription may be seen in Westminster Abbey on the side of a coffin now bedded in the walls of the steps to the Chapter House.

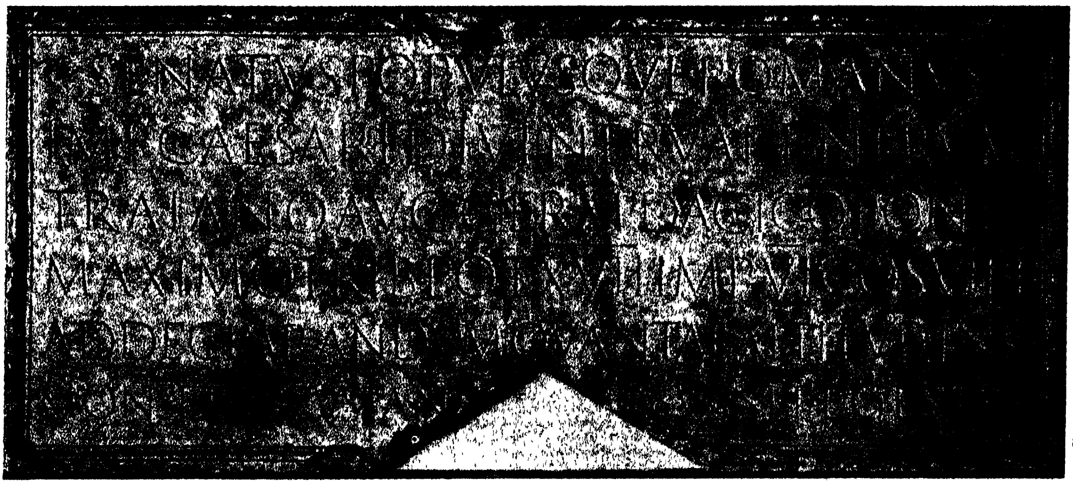


FIG. 21. PANEL FROM BASE OF TRAJAN'S COLUMN

Roman Type. A study of Roman type brings one to the conclusion that a uniformity of form was obtained which, even in the outlying points of their empire, was extraordinary in the absence of any actual standard of reference. The Trajan inscription (*circa* A.D. 117) attracts attention by the beauty of its form and arrangement. It consists of six rows of capitals spaced on a rectangular slab, the uppermost rows cut with a taller character than the lower to correct the apparent diminution caused by the perspective, so that from the ground all the letters of the inscription appear to be the same size. The curves are cut with a sense of great refinement and appreciation; no compasses were used in their setting out. Many attempts have been made to construct a fool-proof compass-made alphabet, but it invariably loses in interest, in shape, and, more particularly, in adaptability in relating one letter to another.

These letters are obviously derived from those made with a pen stroke, as the thick and thin of a broad nib, and this thought will solve many problems when drawing them. These widths

Fig. 22. Examples of Lettering used in Architectural Work

are consistent, except where a very wide letter, with a lot of surrounding "white," such as N or M or O is used, when the thickness is slightly increased to overcome any appearance of comparative weakness. A good method of procedure when studying the form of letters is to make a double line with two pencil-points tied together; the variations then become automatic, and the sweep of the hand more obvious.

CONSTRUCTION. The points worthy of chief note when studying the drawing of letters are as follows—

1. FORM OF LETTERS. Copy the Roman alphabet, letter by letter, making your letters about 2 in. high and using a double point. Note the detailed explanations in Fig. 23.

2. ALPHABET. When the forms have been learnt, write another complete alphabet, making the spacing consistent and comfortable.

3. INSCRIPTION. Write a small inscription, such as the one illustrated in Fig. 25, noting particularly the spacing of the letters in the words and the words in the sentence. Leave no "holes" or "crowded" letters.

4. Having practised the form and spacing of these letters, do them all over again, using only a single line (as with a stylo pen).

5. Practise further large and small versions and, if possible, some smaller script. Whatever you do, however, always keep the same comparative proportions in the letters, whether small or large. Watch good inscriptions, good shop fronts, good posters, advertisements, printed notices, etc., and make notes of them when possible. Spacing will grow on you, and the simplicity of uncrowded pages will please you. Appreciation of simplicity and legibility of design, for innumerable things, will rapidly increase your own powers of discrimination and practical application. Watch all the best drawings, and you will see the same attention to the small informative notes as to the main title of the work. The dimensions will be found to be indicated with the same thought, and the positions of relative words on plans are always considered and planned to produce the least confusion and the most orderly arrangement for the benefit of the reader. Go through all the illustrations in this series, and you will find many points of interest now which had hitherto escaped you, particularly on working drawings, which are essentially the job first, with everything else subjected to its importance. You cannot learn to write in half an hour, and when the essential problem is one of good form in the letter itself, and good spacing in the whole composition, much time may be spent in its execution. Good draughtsmanship is vastly improved by an efficient use of lettering, and no time spent in its improvement and acquaintance can possibly be wasted.

The main characteristics of the Roman letter are their varying proportions, the variation in the thickness of their strokes, and the strong, beautifully drawn, and curved "serifs," or extremities. The Roman inscriptions invariably show us that a regular yet elastic system of proportion was evolved, which, while always keeping to true proportion in the letter itself, yet allowed for variation in width of individual letters to provide for even spacing. Such letters as H, K, M, and T were sometimes narrowed or widened slightly for this reason, but letters which depend on their curves for proportion, such as O, C, D, etc., were never modified in shape.

For general purposes of analysis we can divide the alphabet into two groups, wide and narrow, the wide approximating to seven-eighths of a square and the narrow to five-eighths. The wide letters are: A, C, D, G, M, N, O, Q, V, H, K, U, W, Y, the remainder being narrow. H, J, K, U, W, Y are not contained in the Trajan inscription, but follow the same rules as the other letters.

WIDE LETTERS

A and V occupy a square. The crossbar comes just below the half-way line.

C occupies more than six-sevenths of a square, It is a very difficult letter to draw, being particularly subtle in its curve.

D occupies a square.

G occupies nearly a square; it is much the same as C, with the addition of the upright stem, which needs to be fairly long. The top serif overhangs it slightly.

H (includes I) occupies a square, and can be modified slightly for spacing. Note the position of the crossbar.

K occupies six-sevenths of a square. The sloping members only touch the upright, and their serifs must be kept under control.

M is a little wider than a square. It differs from W in that the outside lines are nearly upright. The inner V should be normal.

N occupies a square, and occasionally can be slightly heavier to counterbalance the sur-

rounding space, particularly when next to any of the curved letters.

O This can be drawn with compasses on the outside line. The inside cannot, and only for the benefit of repetition and neatness should the compass be used, the true letter being not absolutely circular. Note the line of the axis, giving a thickness in the natural position of writing.

E, F, and H, etc., and the V is slightly wider than actual V.

Y fills six-sevenths of a square, and is somewhat difficult to balance. The inner angle of the V needs to be on half-way line.

Z is practically a square, and, like N, can be exaggerated in width for spacing, and in thickness for effect of openings.

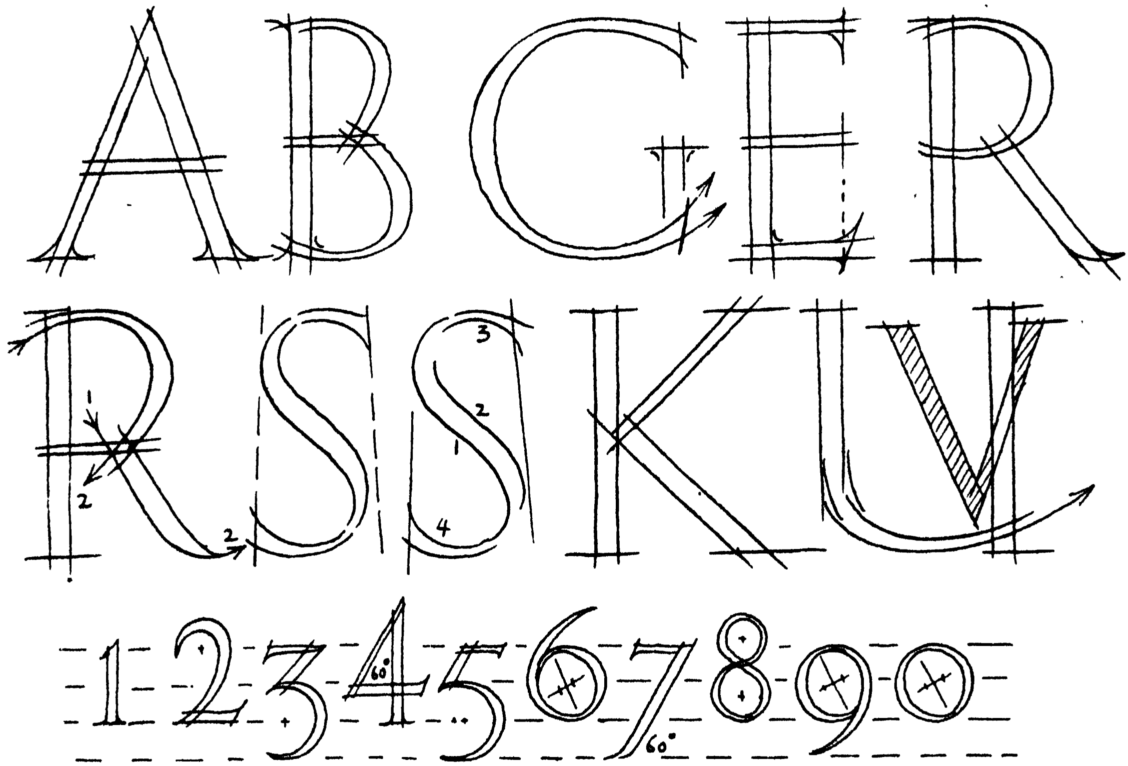


FIG. 23. METHODS OF CONSTRUCTION

Q is similar to O, but the tail can be drawn either straight or slightly curved. It is always a clearly " drawn away " stroke.

U fills almost a square, with the lower curve drawn flat. The Romans invariably used V for this letter, and modern American drawings follow this rule with success.

V and W. The latter is the widest letter, nearly one and one-third squares but, like two normal V's, sometimes interlocked.

X occupies about four-fifths of a square. The lines cross slightly above half-way, like

NARROW LETTERS

B occupies about two-thirds of a square. The lower bow of the letter is a little wider than the upper one, and the modern tendency is to exaggerate this too much.

E, F, and L are approximately equal to half a square ; the serif at the end of lower bar may be slightly extended if convenient.

P and R fill rather more than half a square, the loop being closed just over half-way. The tail of the R varies and sometimes descends just below the bottom line ; this is a very beautiful letter when well drawn, and can be extended if necessary.

S, perhaps the most difficult to draw of all, occupies half a square. The bad modern tendency has been to broaden the S and to narrow letters like O, C, and G, thus weakening their distinctive character. The two curves appear to be approximately equal, but if turned upside down the lower will be noticed as distinctly larger. The centre stroke is very nearly straight in its tendency. This letter must always balance well, and should never be distorted.

T occupies generally five-sixths of a square. Not all the Roman T's have serifs sloping, and later samples favour the vertical serif. This letter can be contracted, if necessary, and the arm was often raised above its fellows to allow of abbreviations, etc.

The alphabet sheet, Fig. 22, is a good collection of different types, and explains itself. Note the natural shape of the pen marks and the method of drawing the serifs. When practising the drawing of letters, get into the habit of taking your lines through as indicated in Fig. 23. The swing of the R, for instance, commences at 1 and "follows through" to 2. Never cut off corners hastily when making the serifs, but let the lines proceed evenly, like railway junctions. Cut each line through its fellow in the cross strokes, until a mastery of the letter has been obtained. The numerals illustrated are of good form, and may be, if necessary, executed with compasses, though a guiding circle occasionally will be found sufficient after practice of the forms and the development of the swinging line, as indicated for the letters.

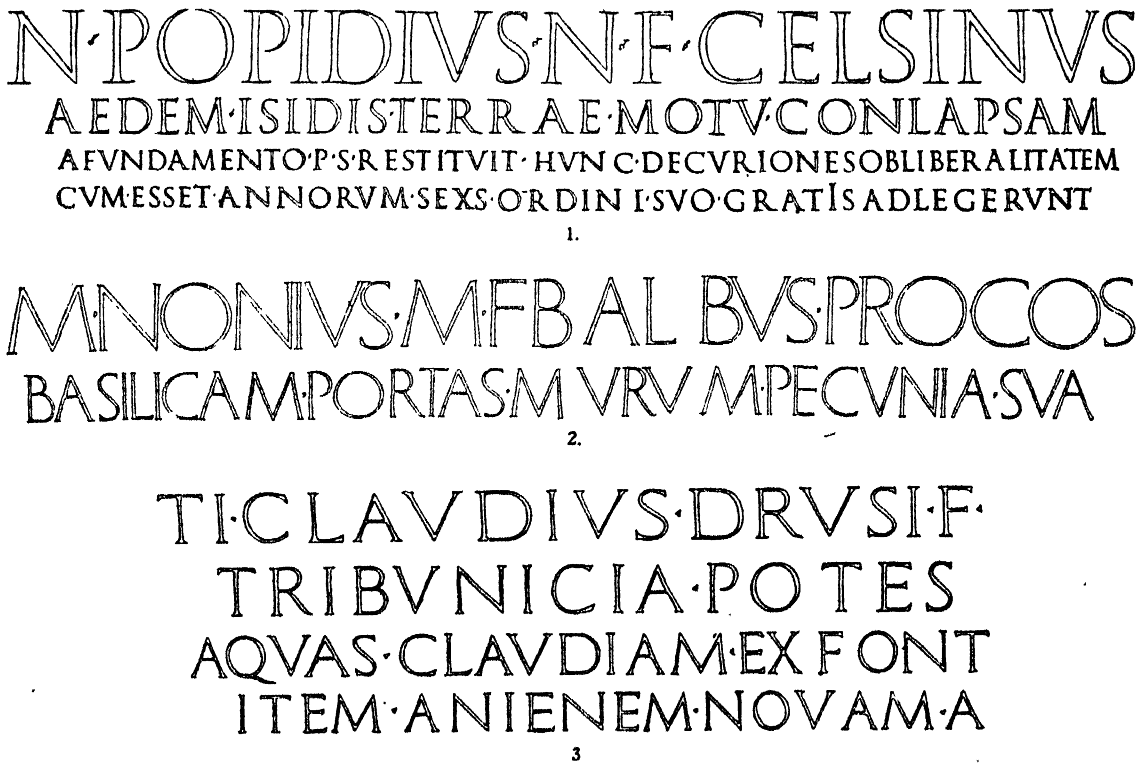


FIG. 24. PAGE FROM HUBNER'S "EXEMPLA"

The Roman lettering from Hubner's *Exempla*, Fig. 24, is an excellent example illustrating the variation of size and height to comply with composition of panel; note the absence of any erratic contractions and the generally beautiful arrangement from the centre line.

The panel "memorial," Fig. 25, is included for spacing, and, being the early work of a student, shows several obvious faults in the thickness of strokes, but very few faults in actual spacing. It is most difficult to avoid the change of thickness, particularly when working

with instruments. The hand-drawn letter is easier to control after a general facility has been obtained. When using instruments, always keep the gauge of the thick strokes, by means of spring bow dividers, set to the required size. When filling in large letters, a good brush of suitable size will be found easier to handle than a pen; work along the outline, always using the flattened point of the brush, never using the back of the brush across the line.

Lettering for Working Drawings. Some men prefer a widely spaced word, and this looks extremely well in some drawings. To arrange for this, set out the letters in the ordinary way in pencil, and then reduce the height by about one-sixth; or tick off on a $\frac{1}{2}$ in. height $\frac{3}{4}$ in. marks, making these the centre lines of each letter, irrespective of wide or narrow. This is a slight affectation, but a "good fault." It must not be allowed, however, to compete with formally spaced letters, i.e. the centre spacing should be considerably more than the square, and the letters should preferably be single line ones.

The practice of lettering is one which is apt to be dismissed lightly by the student, until his office experience compels him to think more highly of those men who can do lettering rapidly and well. It is soon obvious to him that every drawing needs some description, and very possibly a certain amount of descriptive "legend." In the case of working drawings, this requirement is of the first importance, and every endeavour should be made to keep whatever detail has to be explained by notes in an orderly arrangement, in order that the actual drawing and the perception of its details shall not be interrupted by scattered references.

The information already given should be practised consistently until ease and freedom are assured in the drawing of the shapes and the spacing of the letters. Every opportunity should be taken to "letter-up" drawings, and all possible reproductions and examples of contemporary practice should be studied from the technical magazines and elsewhere. Small descriptive "legend" or detail on working drawings particularly should be based upon the same formula as that for formal inscriptions; they should be kept at consistent levels or perhaps in an arrangement of panels. Fig. 26

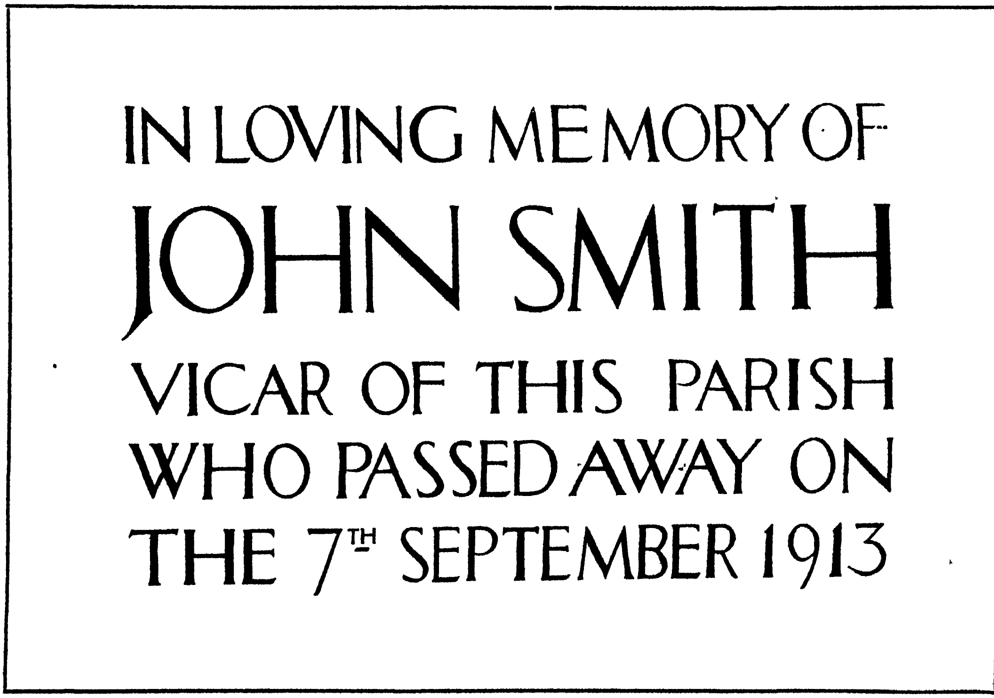


FIG. 25. EXAMPLE OF INSCRIPTION

shows the principles of the formal letters applied to a single line letter. It will be noticed that the shapes are identical with the true Roman inscribed form, and only the thickness of the down stroke and the " serifs " have been omitted. It is advisable to draw these with a round (ball) pointed nib and to use a spring, as allowed to carry a rather more pictorial text the " italic " form is eminently suitable. Fig. 27 gives a good sample alphabet with numerals, and should be practised. It is a good plan when first attempting to form a hand of this type to write them through tracing paper and then practise freely when more assurance has

FIG 26. LETTERING FOR WORKING DRAWINGS

previously described, which will allow of a full line being produced. For the sake of ease and neatness, the circular forms, such as C, D, G, O, and Q, can be turned in with the compass, and this can be extended to portions of other letters, such as B, P, R, U. If this is done, the spacing should be slightly increased to avoid any weaknesses or " holes " between certain letters; the "American" system of very wide spacing is indicated in this illustration. Numerals may be treated in a similar way, and reference to the example will be sufficiently explanatory. Punctuation is seldom necessary in headings.

DESCRIPTIVE TEXT. It will be found perfectly satisfactory to use this form for legends as well as for headings, in which case the size only is reduced as required and punctuation added to save space.

For those drawings, however, which might be been attained. These italics can be written with a spring pen, letter wide or single line, and the thickness of the nib will be found to influence the final character very greatly. Draw guide lines lightly in pencil for the better formation of regular slopes. These italics were much in vogue in the late seventeenth century, and the interested student will find many very fine examples in old books generally, title pages, and the text of engravings.

The last alphabet gives some very fine shapely letters, very suitable for the more decorative type of drawing. These italic capitals mix very well with the small italics, and a glance at an office copy of any lithographed specification will show the great similarity between this form and that used daily by the "copper plate" writer.

Fig. 23, from Hubner's *Exempla*, is reproduced with acknowledgements to the American

Journal *Pencil Points*, a very interesting and enlightening monthly for the draughtsman.

The use of stencil plates for lettering is now a common practice in offices, and is suitable for large-scale drawings, titling, etc. It is, however, a laborious practice except for widely spaced lettering; perhaps selected for its "modern" flavour, it is more suited to the type of unrendered drawing now frequently used.

The smaller letter made with the "universal" stencil plate and round ball nib with fount supply is more appropriate for normal sheets; after a little experience (and some blots) this method is fairly rapid and effective.

Both methods are, however, inevitably automatic and severe in character. It is suggested that a personal application to the suggestions made in this chapter cannot but help the draughtsman in appreciating the character of good lettering in all its many and varied requirements, from those of a temporary "information" character on drawings to the permanent forms of painted or carved lettering required for internal or external architectural application and purposes.

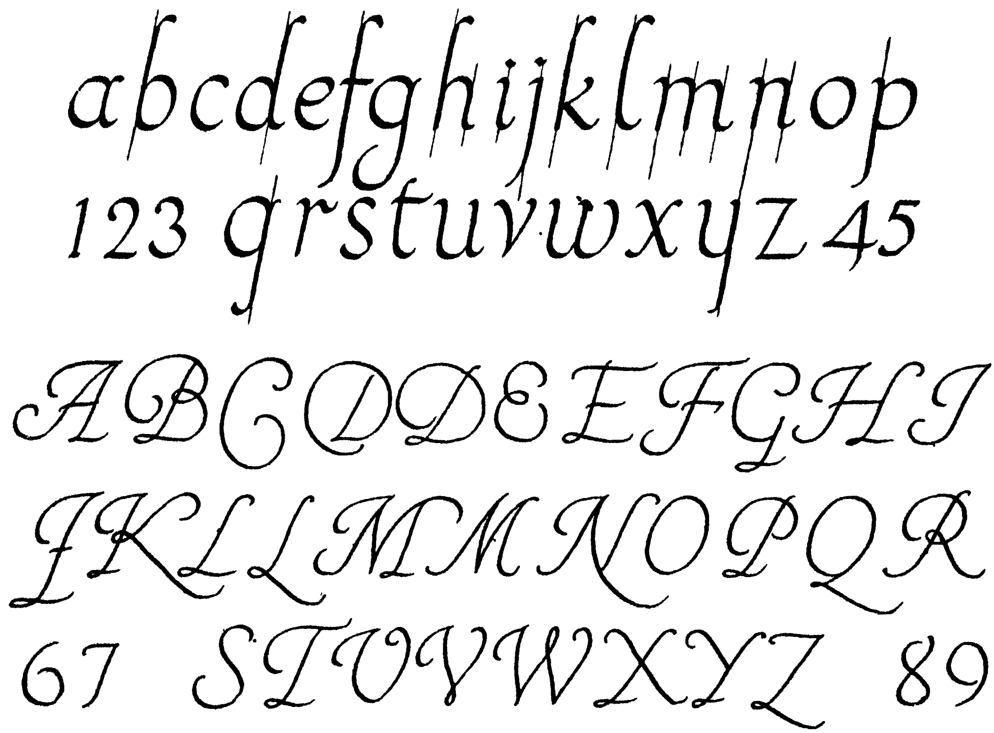


FIG. 27. ITALIC FORM FOR DESCRIPTIVE TEXT

Among the various books to be recommended for further study are—

1. *School Copies and Exercises in Lettering, No. II* (Pitman).

2. *Roman Alphabet and Its Derivations.* ALLEN W. SEABY.

3. *Lettering.* A. E. PAYNE, A.R.C.A.

4. *Writing and Illuminating Lettering.* EDWARD JOHNSTON.

Chapter V—SHADOWS

SEVERAL references have been made in previous chapters to the casting of shadows in connection with the indication of projections or reliefs of surfaces, and we must now consider the

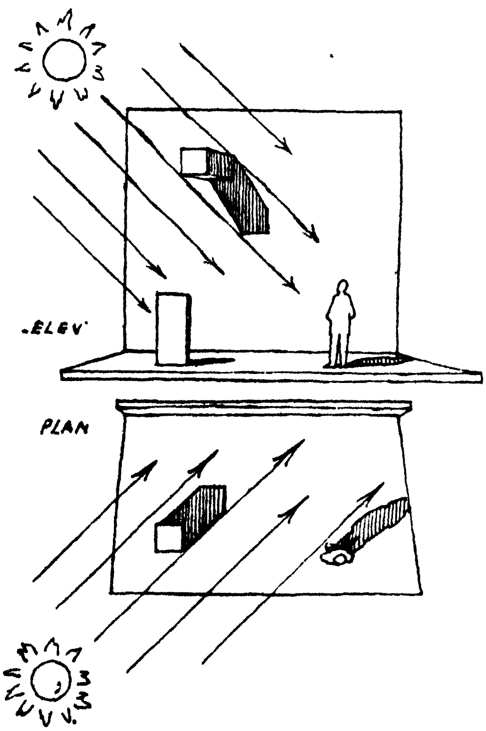


FIG. 28

theoretical procedure for this important part of our subject. *Sciography*, or the theory of shadows, can become a very elaborate study, and is generally associated with the study of perspective. The architectural draughtsman, however, seldom has to deal with shadows when in perspective, and he usually adapts the elevational appearance of the shade lines, cast by theoretical methods, to his perspective form, just as he would any other surface marking. He can get on very well in ordinary practice with a knowledge of projection of shadow points in elevation, section, and plan, for the three planes must be studied together. The simple explanations and exercises given here should be sufficient for all normal problems, more particularly if the student is capable of thinking "all round" a solid form which has three dimensions.

DIRECTION OF RAYS. As in perspective, we have to assume one or two things in sciography. The main thing is that light, for our purpose, travels in parallel rays, consequent upon the vast distance of the sun from us; it also travels from our back, right, or left, illuminating the surface which we are observing. The rays of the rising,

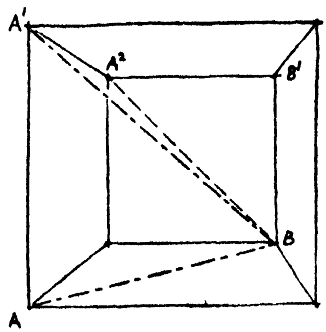


FIG. 29

or setting, sun are obviously very flat, and a memory of a house "lit up by the setting sun" will suffice to show that the shadows hardly exist, the surface receiving light almost at right angles. Similarly a mind's picture of a southern street will bring an impression of extremely deep shadow, the sun generally being almost directly overhead. These brief references will explain the variations, but for the benefit of our practice the chief thing is that we have a set-square of 45° (or 60°) always at hand, as this is obviously more convenient than trying to deal with odd angles of 56½°, 24¼°, etc.

Let us assume, then, that the light of the sun is coming from behind us (left) and above us (left), and put it down as in Fig. 28. This is equivalent to a cube (Fig. 29) through which the light apparently passes on plan from A to B, on elevation from A^2 to B, but which actually passes from A' to B, which is the diagonal of the cube. This assumption allows us to use a 45° set-square for all light rays on elevation, and ditto on plan. One could with a little thought

use 45° on plan and 60° on elevation, or vice versa, but the consequent toil is scarcely worth while in ordinary cases. When the rays are 45° in plan and elevation, the actual angle of the

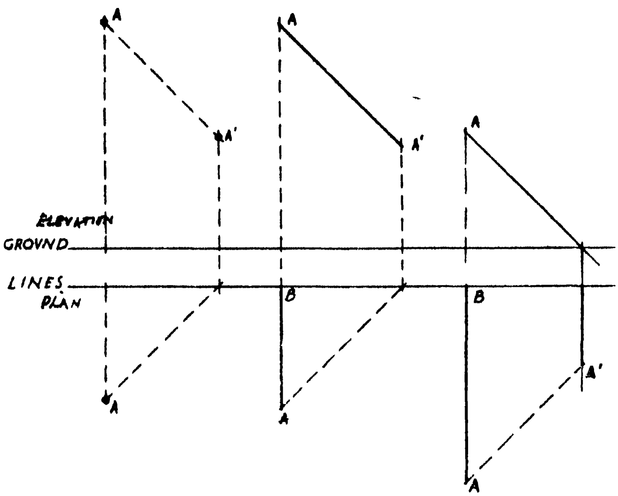


FIG. 30

sun's rays to the plane of the horizon is only 35° 16′. This, however, is of little real significance to us for our particular needs.

The following series of progressive exercises

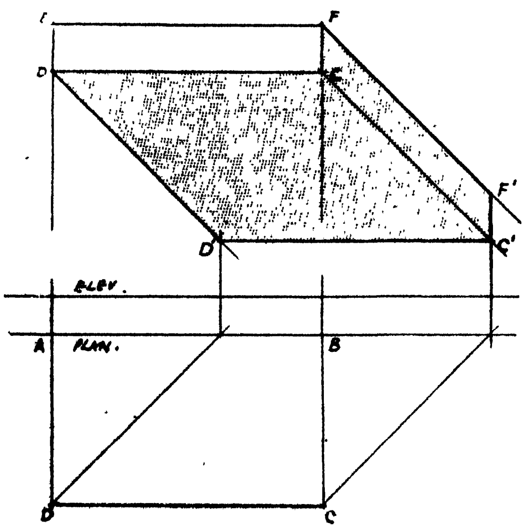


FIG. 32

should be put on to paper separately, and actually tested to solidify the question and to recognize its influence on later work.

Points and Lines. A cane stuck in a wall and in bright sunlight gives a shadow which indicates its form (see Fig. 30). If the end of the stick could have a knob, that knob would be indicated in its shadow, and if the stick

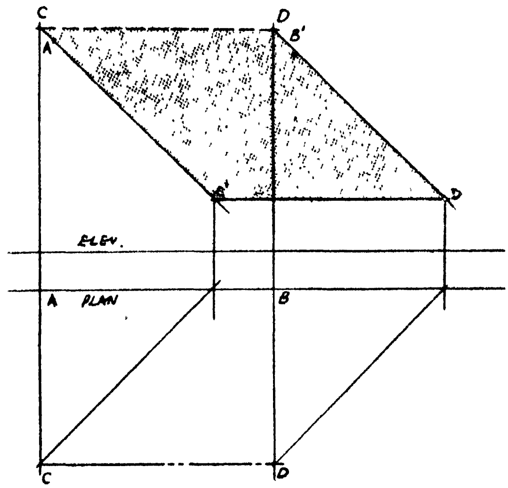


FIG. 31

could be taken away leaving the knob (or point *A*) we should have the shadow of knob *A* only. This would be found to equal a diagonal line drawn from the knob *A*, assuming the stick as one side of a square.

To find the shadow of a small rod *AB* projecting at right angles from a vertical plane. From *A* draw direction of sun's rays (45°) first in both plan and elevation. Where plan " direction " cuts the vertical plane (wall) raise vertical cutting elevation direction at *A′*, which will give shadow point of *A* ; and, as the stick is joined to *B*, so must the shadow (*A′*) of *A* be joined to *B*.

The third example, Fig. 30 is a similar treatment for *AB*, which casts a shadow partly on wall and partly on ground.

In Fig. 31 two level sticks, *AC* and *BD*, are fixed in the wall at the same height. These two sticks cast shadows on the wall, as already explained. If the two ends *CD* were joined by a third rod we should have the shadow of the three rods defined as *A′C′D′B′*.

Having dealt in lines, let us close the space between the wall and sticks and the shadow will also become closed.

A similar case but given a thickness *ED* is shown in Fig. 32 ; proceed as before, noting that vertical *FC* casts a vertical shadow *F′C′*.

Fig. 33 shows the shadow of a line *AB* parallel

to background but not to plan, and Fig. 34 gives the shadow of a line inclined to both planes of projection.

Planes and Solids. Figs. 35 and 36 are similar in treatment to Figs. 31 and 32, but for verticals. Note that *A'B'* is inclined. A similar treatment is required for Fig. 38, which shows a triangular prism. Fill in all shadows where shown stippled with a light wash of colour.

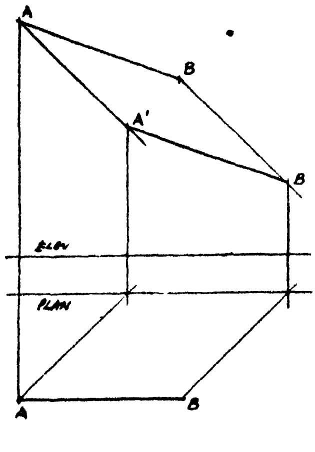


FIG. 33

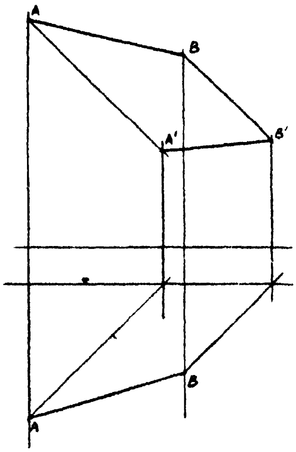


FIG. 34

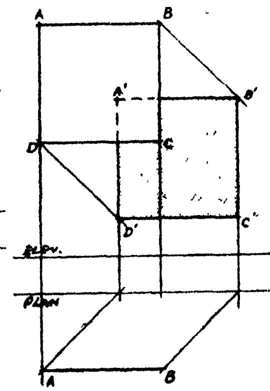


FIG. 35

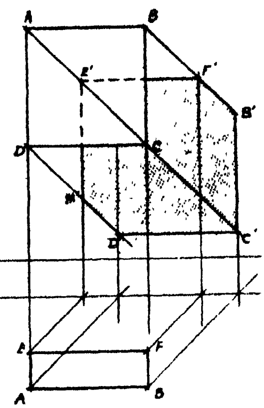


FIG. 36

perpendicular planes. Note that lines parallel to wall cast similar shadows, whereas lines *EA* and *FB* at right angles to wall cast 45° shadows.

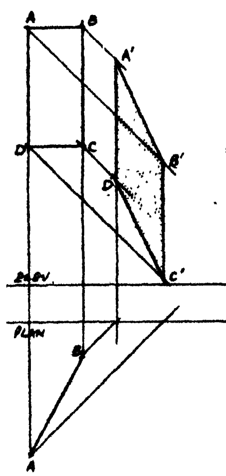


FIG. 37

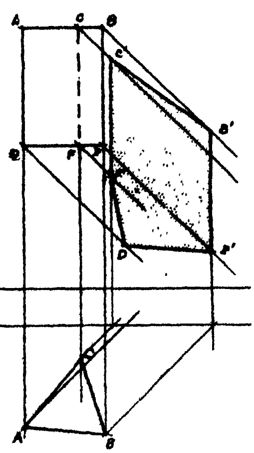


FIG. 38

Figs. 37 and 38 represent eccentric angles to surface of wall, but otherwise are found to be regular in treatment. In Fig 37, *ABCD* is a square plane at an angle to wall. Take direction lines from *AB* in plan to wall and in elevation. Project wall intersections, which will give

If a square casts a square, Fig. 35, a circle will cast a circle, Fig. 39, and for this only the shadow of the centre point is necessary, when a similar radius is employed. An ellipse, Fig. 40,

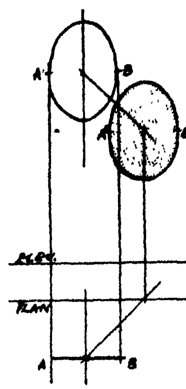


FIG. 40

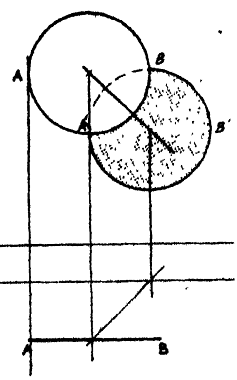


FIG. 39

however, or any similarly irregular form, must be plotted from any points *A* and *B*, from which a similar elevation can be traced.

Cylinder. To find shadow of cylinder *ABC*, Fig. 41, proceed as Fig. 39 for circles. Light passing over the cylinder will be tangential to top and bottom of curves.

These tangent points on elevation can be plotted to plan and cast in the usual way for

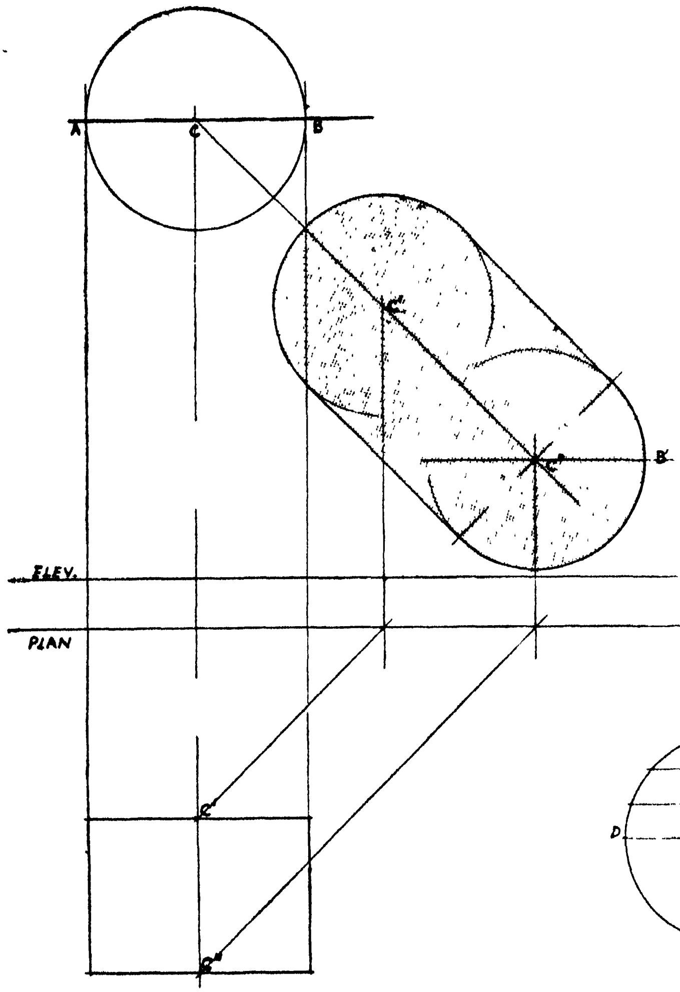


FIG. 41

cases in which extreme accuracy might be necessary.

Circle at Right Angles to Vertical Plane. A circle *BAC*, Fig. 42, at right angles to wall will cast an elliptical shadow, similar to a projected section. For this, construct a half elevation *BDC* and take required *aid lines* across to *B*, *A*, and *C*; drop directions (projectors) from these to meet similar directions plotted from plan, and draw an ellipse through their intersections. See that aid lines are made at equal intervals above and below the centre line.

Circular Slab. The horizontal slab, Fig. 43, will cast two elliptical shadows joined by their tangent lines. Any aids may be taken as geometrical assistance in plotting. In this case an octagon is made and we have the plan and elevation already. Take direction lines from these for one circle; plot the ellipse *AB*; trace one-half and drop to lower level by finding shadow of any point on plan, for example, *B′* to *C′*.

Shadows On and From Steps (Fig. 44). This is an important problem, and though simple has very many different applications. Construct the section of steps from information contained in plan and elevation. Take direction 1 to section at 2, and project to elevation direction at 2. Above, the shadow will be 45°, but below it will be staggered from vertical line. Test this by working backwards from nosings of steps to 1, 1, 1, 1, all within the same ray 1–2. Point 3, however, goes to 4, which on elevation gives direction to 3 Compare plans and alter problem by making balustrade parallel to steps, which gives a

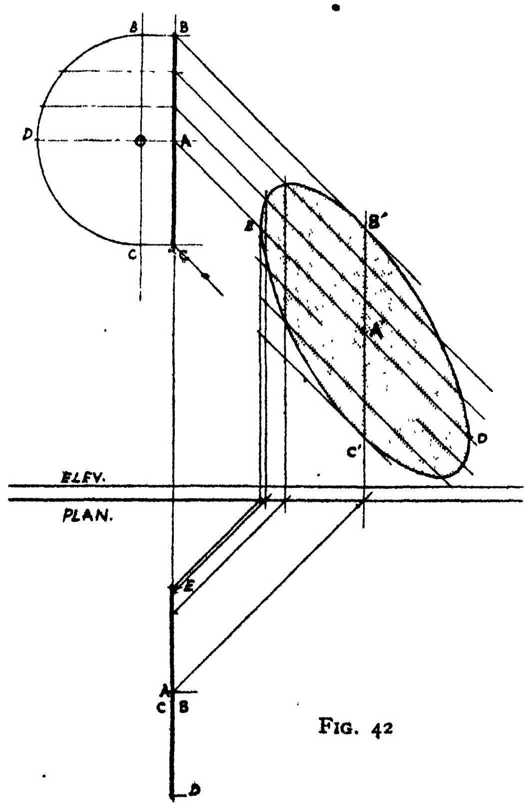


FIG. 42

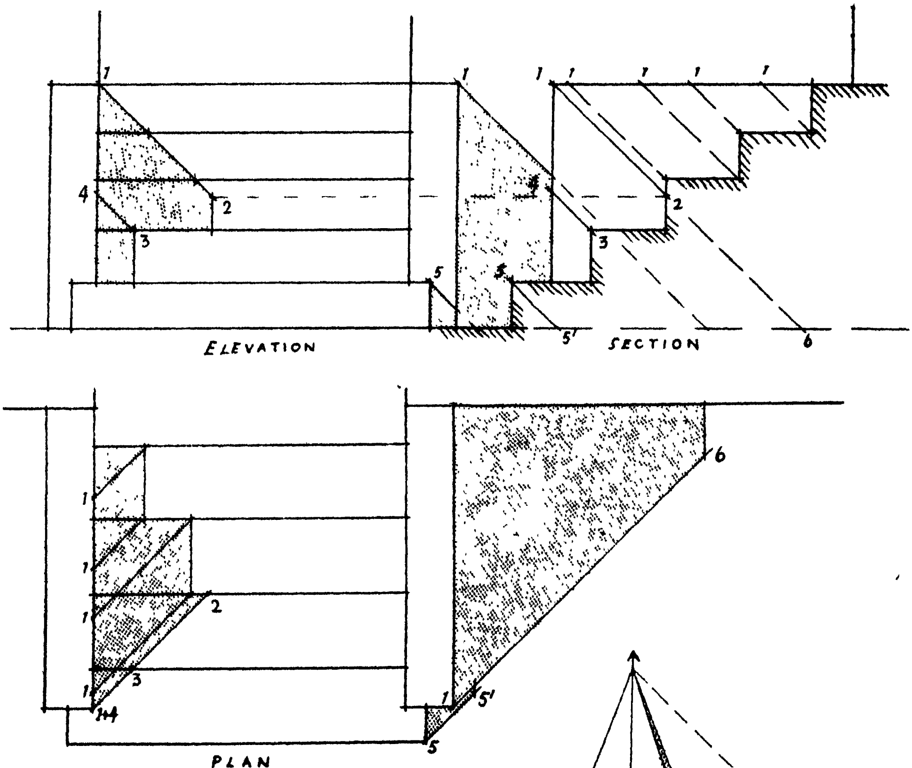


FIG. 44

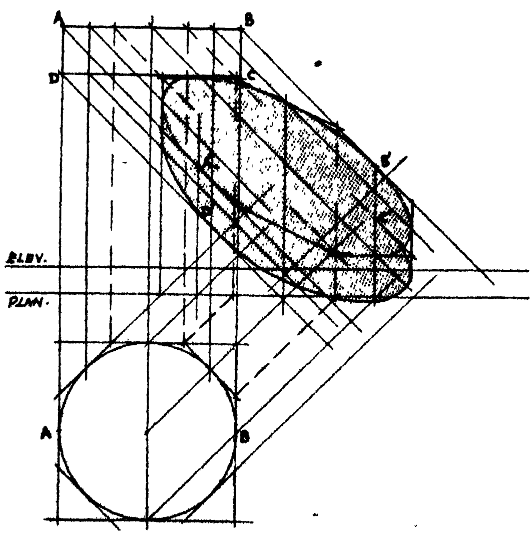


FIG. 43

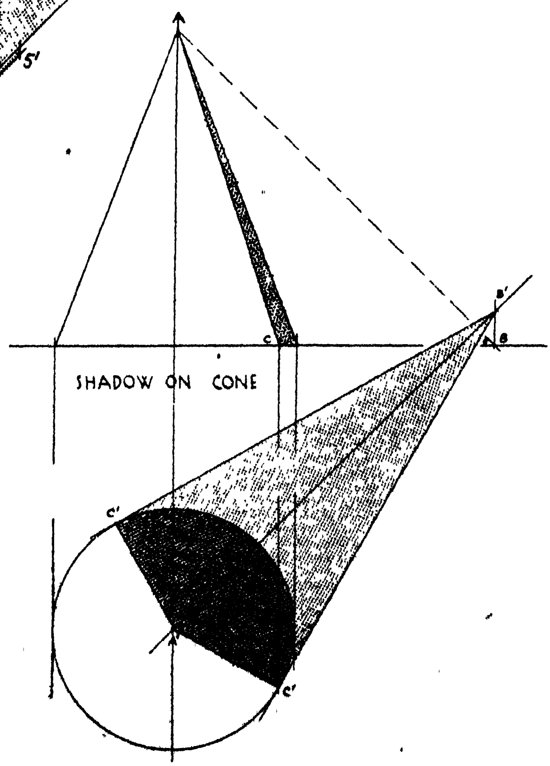


FIG. 45

saw-tooth shadow; or construct with added detail, etc. To find shadows on long flights of steps, test for one average step and repeat; for detailed features, always take the basis of the form first and draw the details around the projected shadow later.

Cone. Take direction of apex A, Fig. 45, on elevation to ground at B, and from plan A' to B' projected up or down from B.

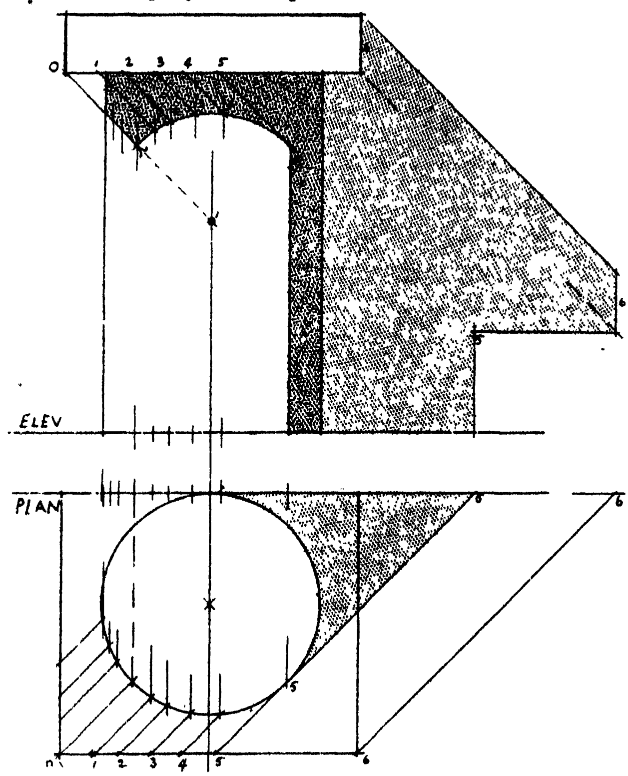


FIG. 46

Join B' to tangents of circle plan at $C'C'$. The area between these points and A' will all be shadow, so project up from C' to elevation C and thence to apex, giving "slip" shadow of amount seen in elevation.

Exercise. Find the shadow on and of an inverted cone; this is the basis of the shadow for the echinus of the Doric Parthenon cap.

Square Slab on a Column (Fig. 46). Take any points 0, 1, 2, 3, 4, 5 on plan of column and on their directions in elevation; project intersections, which will be found to plot the arc of a circle on elevation. Therefore, in future, add the distance of any overhanging line from the circular face to the side elevation at O, and take direction (45°) to centre at O'; then with centre O' and radius equal to the actual column, describe an arc. Tangent point at 5 gives vertical shadow. Note that points at side of plan all plot to 45° elevation OO', and prove again that lines at right angles from background always give a shadow cutting all forms with 45° line. Note this particularly on Doric flutings, etc. A reference to Fig. 47, which shows shadows on square surfaces, will indicate a few of the more obvious shadows, and it is suggested that a similar set of studies should be worked on an imperial sheet of Whatman paper. This sheet can then be retained for rendering at a later stage for practice (see chapter on "Rendering").

Notice that when dealing with "square" shadows, that is, from lines parallel to the surface on which they are cast, forms will be reproduced at the particular distance from plan; a square gives a square, a hexagon a hexagon, etc., and thus any form can be found by ordinary geometric means (or tracing) when once a point of distance has been plotted.

When, however, the forms are not parallel with the shadow plane, all the constructional points must be plotted, and any auxiliary construction must be employed which will aid, for example, in drawing ellipses projected from circles, etc., which contain the required shapes.

Shadows On or From Curved Surfaces. Fig. 48 shows an interesting example of the use of an auxiliary construction. To find the shadow on or from a sphere, the assumption is that any shape which is contained within the form of the object, will also be contained within the shadow of that object. We can, therefore, cut the sphere into horizontal circles 0, 1, 2, above and below the centre line 00. The shadows of these various circles are then found as in Fig. 43, the first circle 00 being followed by 1 and 2 above; the shadows of the lower circles are then traced at their respective levels below. These five ellipses will allow a large containing ellipse to be drawn around them at the tangent points. At a later stage it will only be necessary to find sufficient of these ellipses to discover the necessary tangent points.

Fig. 49 shows a rapid solution of this problem found by experience. The elevation gives its own plan; the tangent points are easily seen

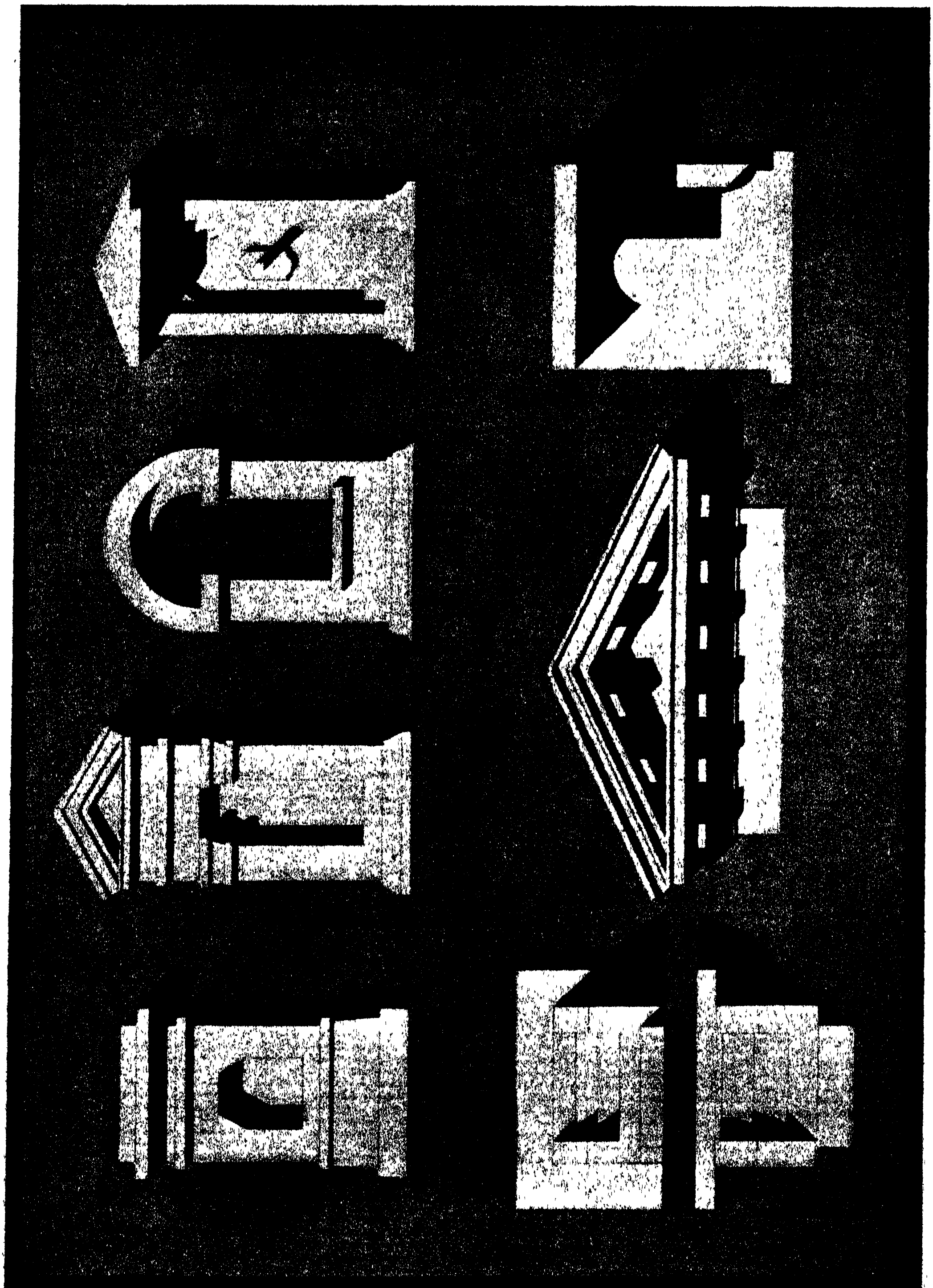


FIG. 47. SHADOWS

and give three points above and below on the circumference and diameter, which are sufficient for the drawing of the ellipse.

Slicing. There are many forms in which it is impossible to find a similar point on plan and elevation, except by means of elaborate projected sections. Such forms are domes, hollows

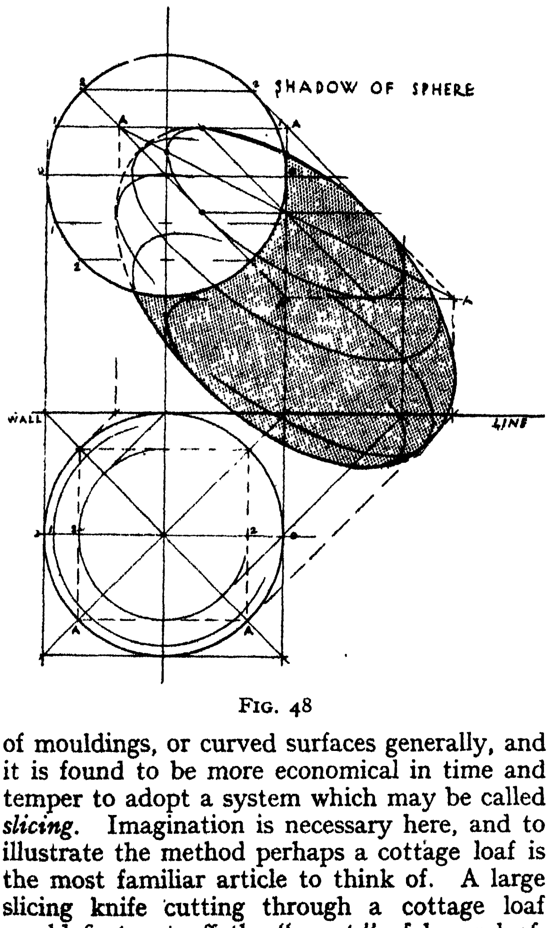


FIG. 48

of mouldings, or curved surfaces generally, and it is found to be more economical in time and temper to adopt a system which may be called *slicing*. Imagination is necessary here, and to illustrate the method perhaps a cottage loaf is the most familiar article to think of. A large slicing knife cutting through a cottage loaf would first cut off the " crust " of lower loaf, then perhaps a small " upper crust," passing on to the next slice of lower loaf. Then a piece of upper and lower joined together, etc., each slice having a changed outline, which would have a spot above and below where the tangent rays would divide the portion in light from that in shade. If, therefore, we can find these slices in any given shape, we can find the necessary tangent spots, and draw, through a sufficient number, the resultant shadow line.

SIMPLE EXAMPLE OF SLICING. Fig. 50 gives the elevation of a simple base moulding, which is drawn with coarse curves for the purpose of demonstration. Draw plans of all principal parts, as at 7, 4, 3. The only other plans available are at 6, and possibly 1. Therefore, cut elevational sections at equal points above and below 5, 2, 3. Economy of plan is good for working. Find plans of these, numbering as drawn, and draw 45° slices on plan at convenient places (experience will assist this decision). Project the intersections of plan to elevation, as at 17, 16, 15, *a*, 14, 13, 12, 11, and draw resultant curve of slice, always continuing this through all necessary forms. Point 13 will be found to overhang the curve, and a direction 45° will strike its shadow a little lower than point 12. Continue these slices as necessary, finding the shadow of the overhang to enable the resultant shade line to be drawn accurately. At approximately point 15 we have an outside curve which gives tangent shade. Continue these in the cyma (base) as necessary, and the smallest ellipse will approximate to the smallest slice of the loaf, whereas the slice next but one will probably have a partner higher up in the form which might cast shade upon it. A careful study and plotting of this example will explain many points of value for later study, and many short cuts will be discovered with practice. Always tint in the shadows, as drawn, with a faint wash of colour.

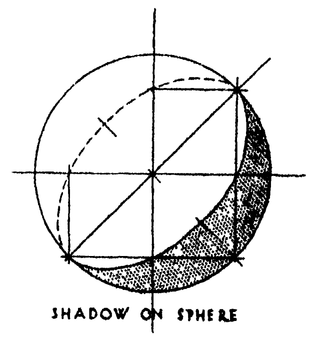


FIG. 49

Niche. The shadow on a semicircular niche is another enlightening exercise in slicing, Fig. 51. In this case we can, by the " spot " method, find shadows of *A* because we have the plan of the surface receiving the shade (the semicircle). By trial and error, we can also find shadows of *B* and *C*, but above this (springing of niche) we have no actual plan line, and must proceed to make them. On the plan draw plans of vertical slices at *N*, *M*, *K*, and erect elevations of these on the right-hand side of the niche. Think of the portion where shade will fall: we have drawn as far as *C'*, and the top tangent *T* must be the extreme point where shadows join the light of elevation. Cut slices on plan between *C* and *T* and project intersections on plan to elevation of semicircle, as at *D*, 2, 3, 4. Draw a curve through these points, beginning at *D*; and

continue through to the upright portion of the niche. It will be realized that this curve is really the elevation of slice *D*, from which point a 45° ray will cast a shadow point as shown. Continue with other slices as necessary (more slices mean more accuracy), and the final curve will show as from *A′*, *B′*, *C′* up to *T*. Below *A* the shadow is, of course, vertical down to the base; then, at the foot, as from *A′* to *A*.

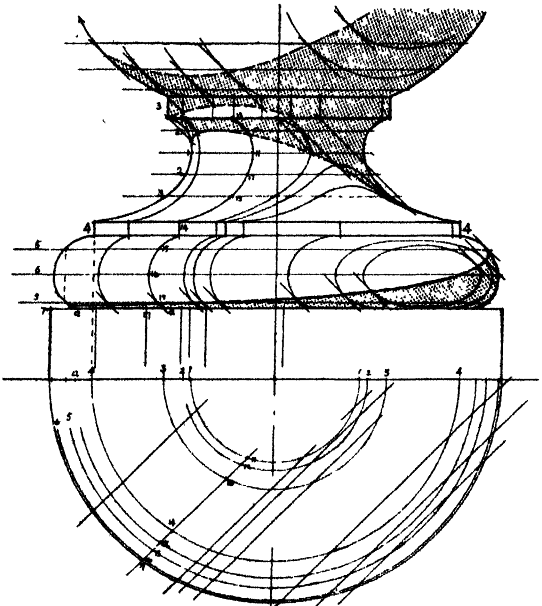


FIG. 50

Curved Surfaces. Fig. 52 shows some elevations of these exercises, and they should be worked out as suggested for the previous plate in preparation for rendering. "Square" shadows change very little, but in those on round surfaces a great deal of reflected light is visible, which must be taken into consideration.

This subject is obviously extensive in its range, and the student should refer to standard books for further detail. The information offered here, however, should assist him in the majority of ordinary cases, and much practice and observation is necessary before control can be attained. Among the books available are Gwilt's *Encyclopaedia of Architecture*, with a very good treatise on sciography, Vignola's *Plates of Architecture*, McGoodwin's *Shadows*, John M. Holmes's *Shadows*, and the plates and reconstructions drawn by students of the French Ecole des Beaux Arts, or those of D'Espuoy.

Every opportunity should be taken to render drawings after the shadows have been cast, and many of the plates in this series will be of value for this purpose. Watch the shadows on walls from cornices or from overhanging eaves, chimneys on sloping roofs, and upright walls, and note the character given to a surface which has finely proportioned shadows, also how these shadows change over the varying materials, such as brickwork, plaster, rough cast, foliage, timber,

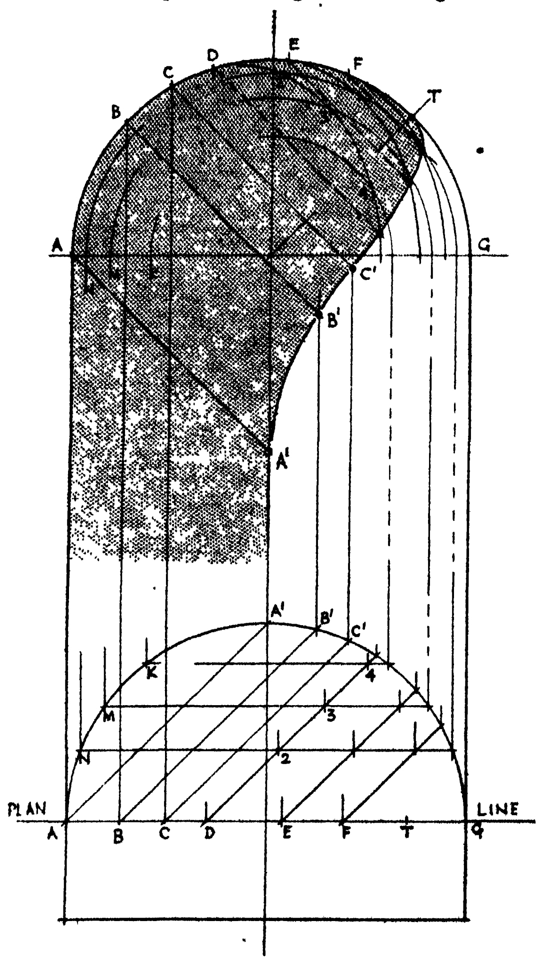


FIG. 51

etc. The student will then begin to realize the subtleties of draughtsmanship, and understand the various properties of tone and the many changes it undergoes owing to light reflection, texture, or colour. His work will then take on a new flavour, and the freedom of thought allowed will be of great assistance in design and all creative work.

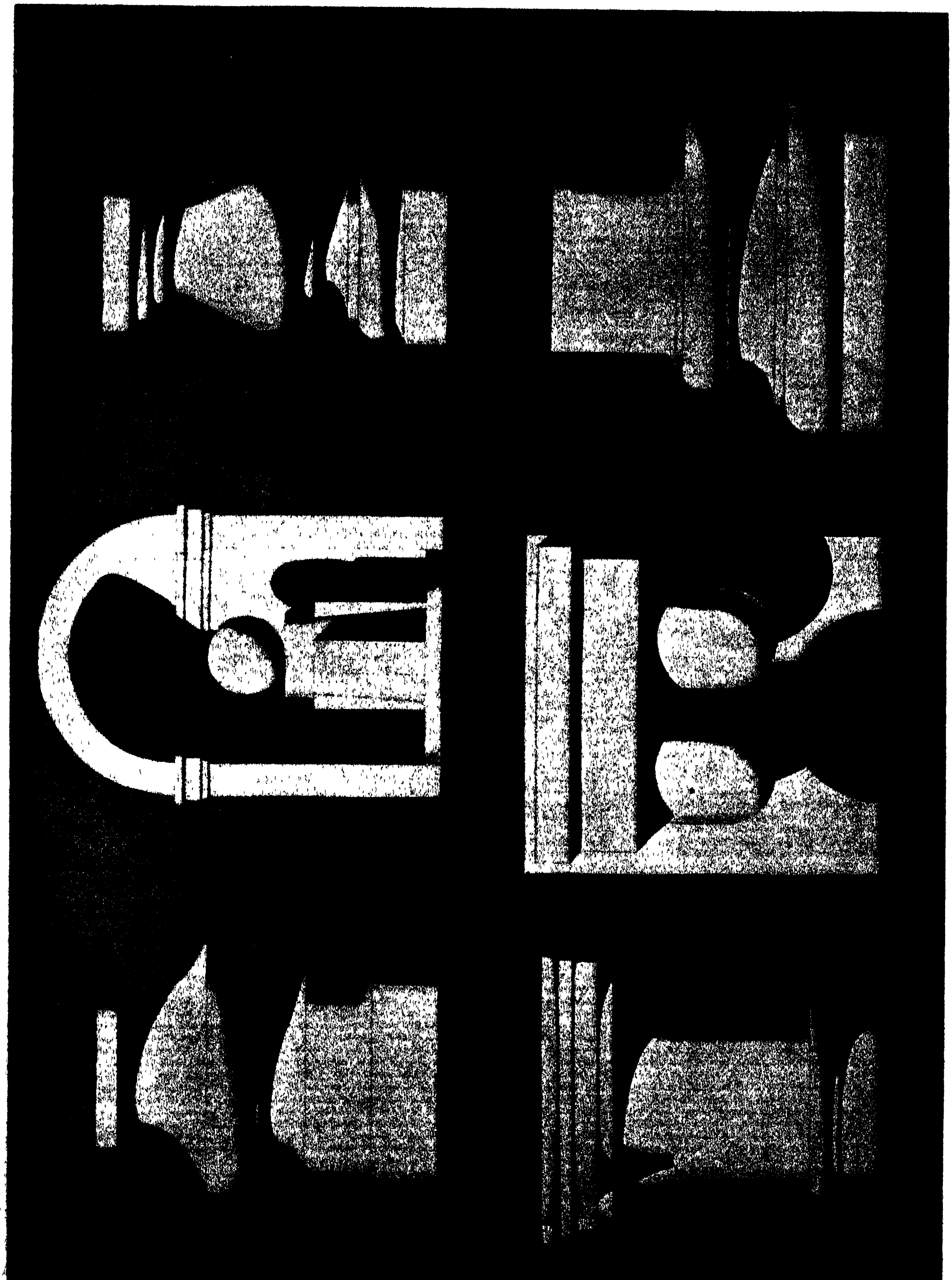


FIG. 52. SHADOWS ON CURVED SURFACES

Chapter VI—PERSPECTIVE

THIS subject is arranged in three sections; the first (Principles of Perspective) offers the necessary preliminary information to explain working methods and exercises which illustrate the essential technique. The second section (Working Examples) indicates a few of the more obvious treatments which can be achieved with normal capacity. The third section, which has been given a chapter to itself, has been written by Mr. F. E. Green, A.R.I.B.A., to

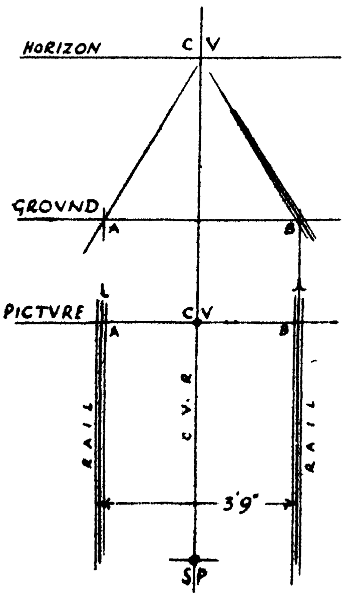


FIG. 53

explain the problem of a small perspective job. The client wishes to see his scheme in a pictorial view, and the various stages in the production of a "perspective" are shown.

In this chapter the necessary information must be abstracted from the architect's drawings and, although the matter can be indicated only very briefly, it is suggested that all the examples should be worked out by the student. Further information can be obtained from textbooks on the subject.

In dealing with perspective theory the following abbreviations are in common use, and should be indicated on all preliminary drawings for easy reference.

S.P.	= Station point	C.V.	= Centre of vision
V.P.	= Vanishing point	C.V.R.	= Central visual ray
P.P.	= Picture plane		
M.L.	= Measuring line	H.L.	= Horizon line
H.	= Height line	G.L.	= Ground line

Principles. The easiest way to understand the science and art of perspective may be, perhaps, to begin with one or two common observations. Looking through a window at the open country, one could draw with a brush on the glass the various objects seen, for example, the distant hills, church spires, a house close to or far away from the observer, etc., yet we know that these objects are actually very much larger than they appear on the glass. Again, the telegraph poles on a road get smaller and smaller as they are farther away, yet we know that they are actually all the same height. On the sea the ships of equal types appear different sizes when seen from the shore, and the horizon is said to be on our eye level. From the process of these observations, then, a method of drawing has been evolved which may accurately express these visual effects.

Everything, then, which recedes from us appears to vanish to some point on the horizon, and to start from our *station point* (S.P.) or feet. Things which are actually higher than our eye level appear to vanish downwards to the *horizon line* (H.L.), and those which are below the eye appear to vanish up to the H.L. If, however, we want to show these effects we must revert to the window or screen and draw upon it, choosing how large or how small our picture has to be, and what it must or must not include. This screen held in front of us is termed the *picture plane* (P.P.), and though invisible it is assumed to be illimitable and vertical, so as to avoid any distortion in drawing. Assuming that this plane is held up in front of us, the eye level becomes our H.L., and the point at which we look directly becomes the *centre of our vision* (C.V.); the path of our "gaze" might be termed the *central visual ray* (C.V.R.), which we shall only be able to show on plan. The junction of the P.P. with the ground is termed the *ground line* (G.L.), and behind it, away

from us, come the materials for our picture. Let us put these deductions into plan and elevation.

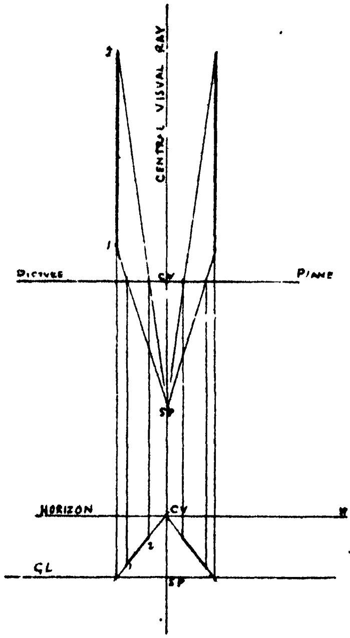


FIG. 54

Imagine that we are standing on a railroad track, Fig. 53, between a pair of rails, and looking directly over the sleepers in the direction

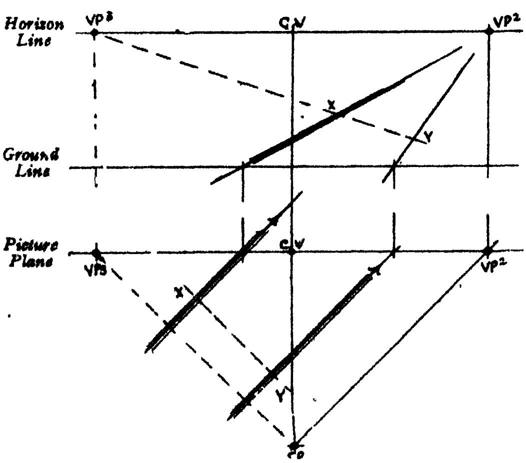


FIG. 55

between the rails. Assume that they are on a 2-mile or 3-mile straight run. Look at the sleeper on which you are standing and note its gauge (say, 3 ft. 9 in.); raise the eyes slowly, looking at each successive sleeper until you cannot distinguish any more separately. Looking up farther the rails appear to converge

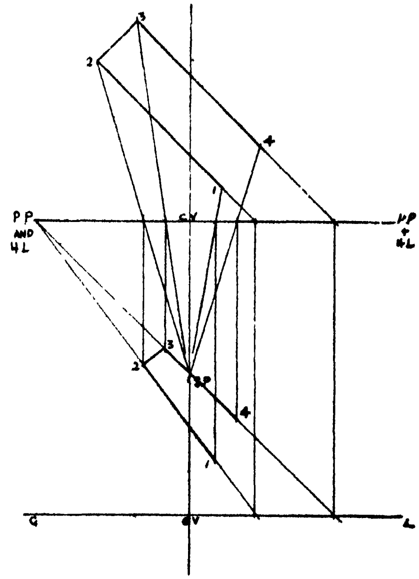


FIG. 56

to a point on the H.L. (our C.V.), though we know that the gauge is constant, however far they may run. We could also say that because these lines at right angles to our P.P. appear to vanish to our C.V., therefore the V.P. is drawn from us parallel to the lines until it touches the H.L., and our plan becomes as Fig. 53. This is important, because we adopt a similar method when finding V.P.'s for lines *not* at right angles to the P.P.

Fig. 54 is another view of the same principle, line 12 and its fellow being brought back to the P.P., taken to elevation, and joined to C.V. Points 1 and 2 within the picture can be joined to S.P. direct and projected down to elevation until they meet the perspective line 12.

Now turn half left and look at the lines so that they cut across our view to the right, Fig. 55. To find the V.P. of these lines, put them on plan and draw a line from S.P. parallel to them, cutting P.P. at V.P.^{2} Mark on elevation G.L. points where lines intersect P.P.; measure off the distance from C.V. to V.P.^{2} on to the elevation H.L., and take lines to it. Any lines may be found in this way, right or left; *always* by drawing a line from self (S.P.) parallel to actual lines on plan.

Fig. 56 is similar to Fig. 55 in method. Points

1, 2, 3, and 4 on the receding lines are found, as in Fig. 54, by joining to S.P. on plan and

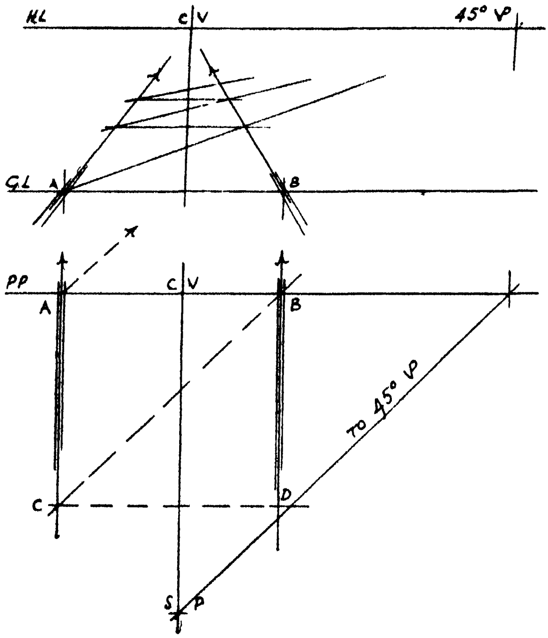


FIG. 57

projecting down to elevation until they meet their respective lines.

The next problem is to find details within the picture by actual measurement. If it is desired to put in, for example, some of the sleepers between the rails, we can measure off squares ladder-like within the two rails. To find a distance equal to AB, Fig. 57, take a 45° diagonal line from B to C and assume CD as a sleeper, which is similar to AB and other sleepers within the picture. Find V.P. on plan for CB (45° from S.P.); all lines parallel to CB will vanish on elevation to V.P. of CB. We are thus using the diagonal line of a square in perspective as we should do in actual board work to construct innumerable squares. To measure similar details in the case of Fig. 55, draw XY as one of many sleepers on plan; find V.P. for XY (V.P.[3] from S.P. parallel to XY), and project to elevation. Join S.P. through X to the P.P., project to elevation, and proceed as for Fig. 56; the elevation of XY is shown for convenience as if it were a sleeper within the picture, i.e. on the other side of the P.P. from the S.P.

Sometimes the lines we wish to draw are so flat (nearly horizontal) that it is very inconvenient to find the V.P.'s for them. Fig. 58

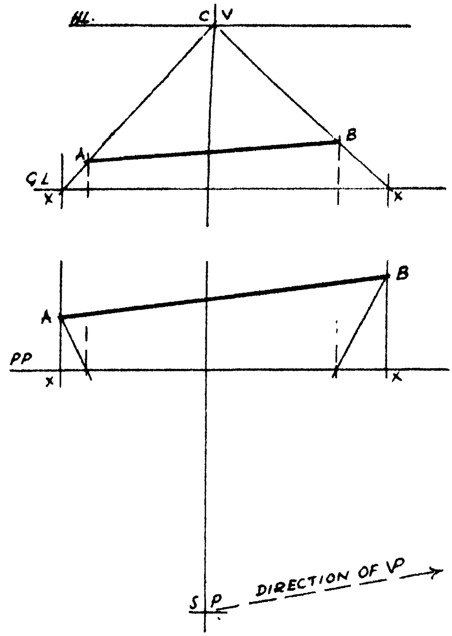


FIG. 58

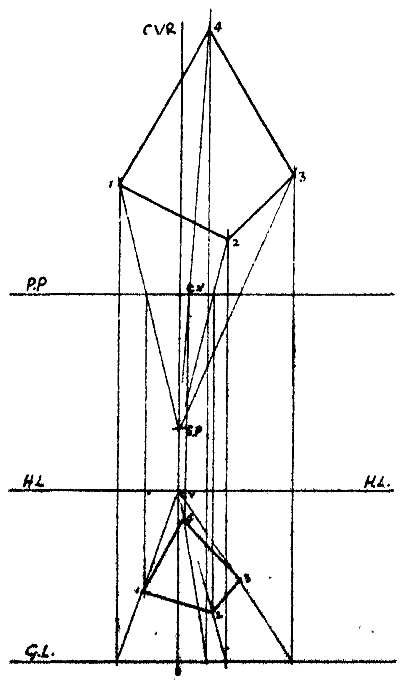


FIG. 59

shows the line AB in such circumstances. Assume that A and B are two points within lines at right angles to P.P., and put these lines in perspective as Fig. 53. As all objects appear to pierce the P.P. at definite points when joined to S.P., we can join A and B to S.P. and drop their intersections with P.P. to our elevation at A and B. Join A and B. This method can be used for all odd lines, but is obviously a longer procedure than before.

Fig. 59 shows the application of the principle given in Fig. 58. To find the shape 1, 2, 3, 4 in perspective, drop verticals to P.P. from all

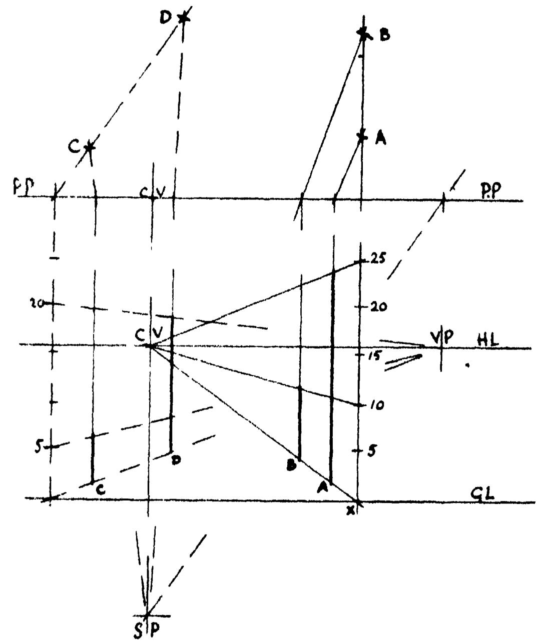


FIG. 60

points, projecting them to elevation G.L. Join to C.V. Join 1, 2, 3, 4 to S.P., and project intersections with P.P. to elevation lines; join up as at 1, 2, 3, 4.

We can use this principle to measure heights. This is explained by Fig. 60, where we assume a flagstaff 25 ft. high at A within the P.P., and ourselves at S.P. No lines are already in use; therefore drop a line at right angles to P.P., and mark off on elevation from G.L. at X. Take to C.V. and find A as before. The vertical above X is the junction of picture and object, and can be used for actual measurement. Make a scale of feet on this line and, marking off 25 ft., take to C.V., cutting a vertical on A at similar (i.e. perspective) height. At B is a similar pole 10 ft. high. Others at C and D, however, happen to be on a line passing through to P.P. Take a line parallel to CD from S.P., giving the V.P., and use in similar manner, having erected scale as before. It is purely a matter of convenience so long as the correct V.P. is used.

Fig. 61 shows how to construct a square on a line AB, with two more added squares. This procedure is as for T-square work. Drop verticals from AB to P.P. and elevation G.L. Take to C.V. Through A draw 45° diagonal and find V.P. in elevation by taking diagonal to

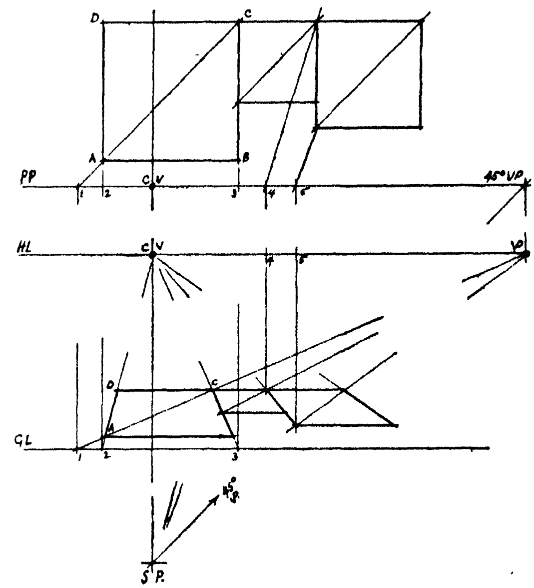


FIG. 61

V.P. For adjoining squares join either distances as shown to S.P. at P.P. 4 and 5, using 45° diagonals as before. This sort of problem is extremely simple and allows for speed in operation to be obtained. For this purpose the student should work through these various problems, adding others as they are suggested and always applying them, if possible, to some practical shape, for example towers, church spires, doors, or features of any sort, noticing all possible points in actual outdoor experience.

Small House in Perspective. We have now sufficient information to be able to set up a small house form. It will be noticed that in many cases the diagrams show the elevations drawn on top of the plans and between the P.P. and S.P. This is purely for convenience in

plotting exercises, but is obviously not always possible. The office practice is to have the plan given in the form of a tracing or print, together with sufficient elevational detail, obviously too large for comfort in working. It is always wise to settle the disposition and design of the drawing by means of a small diagram worked as in these illustrations. This can be enlarged later and easily altered as desired, but it serves the very useful purpose of allowing a general sketch to be made to a small scale on which can be tried out the various accompaniments to a building, for example, traffic, figures, colour, light and shade, atmospheric effects, etc.

Having decided on the position of S.P. and P.P., Fig. 62, lay the plan on one board with

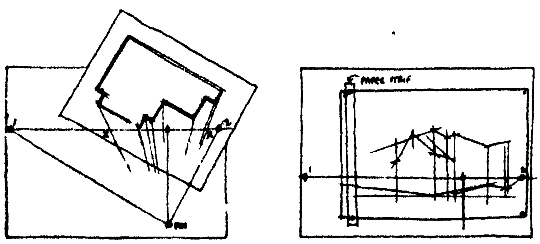


FIG. 62

P.P. parallel to one side for convenience, and join main extreme points of plan to S.P. as shown. Find V.P.'s for house and arrange the paper so as to get as much of the work as possible on the board. Set up on another sheet the H.L. and G.L., having decided where the mass of the picture shall come in relation to the V.P.'s. On the H.L. mark off first the C.V. and then the points *XX* and V.P.'s. Carry on then as before and as explained in Figs. 55 and 56. Take off all information from plan on a " tick strip " of paper, always registering at one mark—the C.V. Experience will teach rapidly; and after transferring the main angles of the house, take all windows and doors, ground floor, first floor, and roof level, from the plan in succession and *only* as required.

Fig. 63 shows a plan of a house with its two outhouses and roofing. Having decided to show sides *A* and *B*, choose S.P. in order to view the principal parts of the house. A good useful rule for the distance of S.P. is three times the height of building. This position is due to choice of view, but the angle of vision available (i.e. the "picture") should be that of normal sight, that is, 60° horizontally and 45° vertically, and should not be exceeded, otherwise some distortion is probable. The position of the P.P. is also largely a matter of choice, and reference to Fig. 63 will show that if it be moved forward a large picture will result; while if brought nearer to S.P. the V.P.'s will become closer, and the picture will become smaller and the house somewhat distorted. To enlarge any details on the present P.P., reference

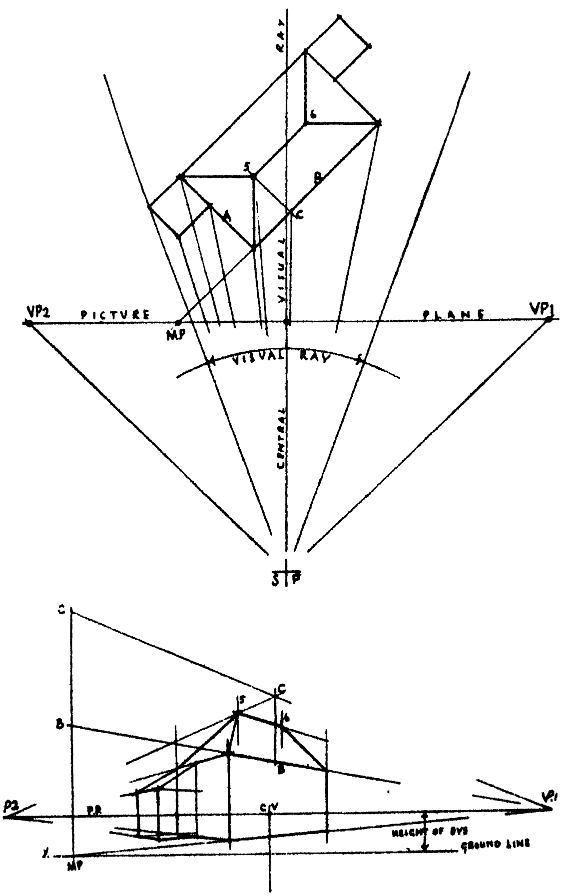


FIG. 63

to the diagram will suggest that another line behind the house would, for instance, double the size of the containing arc. This arc (in Fig. 63) should be called " angle of vision " rather than " visual ray." When enlarging always enlarge everything—height of eye, V.P.'s, dimensions, and height line.

The procedure for this house is obvious from the diagram. For the roof the method shown is only one of many possible methods. From hip 5 take 5*C* parallel to *A*. Find *C* on elevation by

adding height *BC* over M.P. (acting as measuring or height line).

In practice it will be found convenient to collect all features on to the plan by making various tracings, of different levels or features, which can be slipped on to the main plan as required. The actual setting up of small details

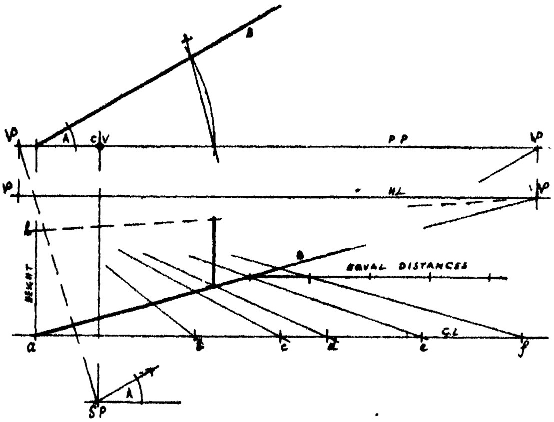


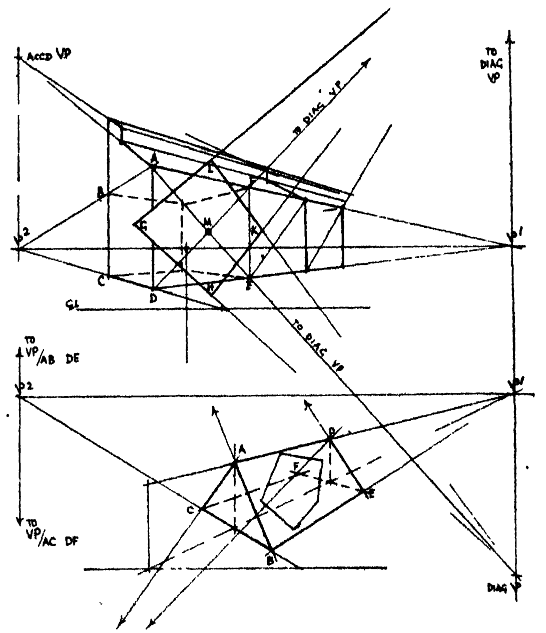
FIG. 64

is not necessary and, apart from being very laborious, is not so accurate as finding the main dimensions which can be amplified by hand upon the drawing. An $\frac{1}{8}$ in. scale plan usually produces a very small drawing and it is better to double all dimensions, as necessary, when working upon the finished sheet rather than to enlarge the plan itself.

MEASURING POINTS. Fig. 64 gives a method for measuring any distances *ab*, *bc*, *cd*, etc., on the line *AB* produced. With centre *A*, on plan, and any radius, describe an arc cutting P.P. and *AB*. Joint the intersections and find the V.P. for this line. If lines are drawn from *b*, *c*, etc., to this V.P., these lines will be the perspective representations of lines parallel to our arc line. When it is desired to increase equal distances, a new scale can be set up inside the picture as shown.

OBLIQUE PLANES. To avoid the complications usually attendant upon the study of oblique or accidental planes, Fig. 65 should be studied. A cubic shape *ABCDEF* in perspective shows the two sides vanishing, as usual, to their respective V.P.'s. It will be realized that the third square plane is under similar conditions to *ADEF*, and that a line drawn anywhere on this square would be on the same *plane* also, and would, therefore, vanish to the same direction if not the same actual point. Imagine square *ADEF* pivoted about its centre *M* in the position indicated. The new square *LGHK* is still in the same plane, and obviously vanishes to V.P.^{1} up or down, in this case parallel to diagonals and to same V.P. as for the diagonals produced. The height of such V.P.'s can be found by drawing the angle of the required height from S.P. to cut a line from present V.P. at right angles to line S.P. – V.P. Transfer this height to a vertical over V.P.

Fig. 66 (below Fig. 65) is based on similar principles, the face of the prism *ABED* vanishing to V.P.^{1}, and any lines on that face to same V.P., up or down. Any shapes or lines (e.g. the irregular pentagon shown) will vanish to V.P.^{1}, up or down, and similar rules can be developed as for the early exercises noted in this lesson. Such V.P.'s are not worth troubling about for ordinary purposes, but they become extremely useful for continuous forms, such as roofing tiles, dormer windows, hips, intersections, or details of projections, buttresses, etc. A 45° V.P. is



FIGS. 65 AND 66

always useful; and if a similar one is found for height, shadows become simple things to apply to the surface.

These points are the principal ones contained in the science of perspective, and are not difficult to grasp or to apply mechanically. That

the draughtsman must be completely familiar with them is obvious, for they complete his equipment, without which he cannot work. He must realize, however, that his skill is measured, not by this knowledge alone, but by the use he makes of it in pursuit of the art of perspective, an aspect of draughtsmanship that will be dealt with in the next chapter.

The working examples included here should be studied carefully as they show a variety of the methods adopted in the solution of particular problems.

FIG. 67. A TOWN MEMORIAL

Working Examples

Wash Treatment : A Town Memorial. Fig. 67 is a view selected to bring out the principal features of the design, while expressing the local character of the surroundings. It is an interesting example of simple wash treatment over a carefully detailed drawing. Note low position of eye level to create due scale, and simple treatment of background with heavy sediment wash relieved with simple roof detail. This scheme was rendered with heavy wash first: stonework sponged out, background strengthened, and shadows made crisp and sharp to emphasize material. Actual size 22 in. by 20 in.

Pencil Wash. Fig. 68 is a perspective of a modern shop in Regent Street, London, and is an angle treatment necessitating a great amount of detail. It is greatly strengthened by the composition of the foreground and of the figures in shade, which increase the effect of stone texture. Note low H.L. here also for large effect, and to emphasize "business" of traffic. This drawing was made in strong pencil line, with thin delicate washes applied, and toned up with pen detail on the windows and figures. Size about 25 in. by 18 in.

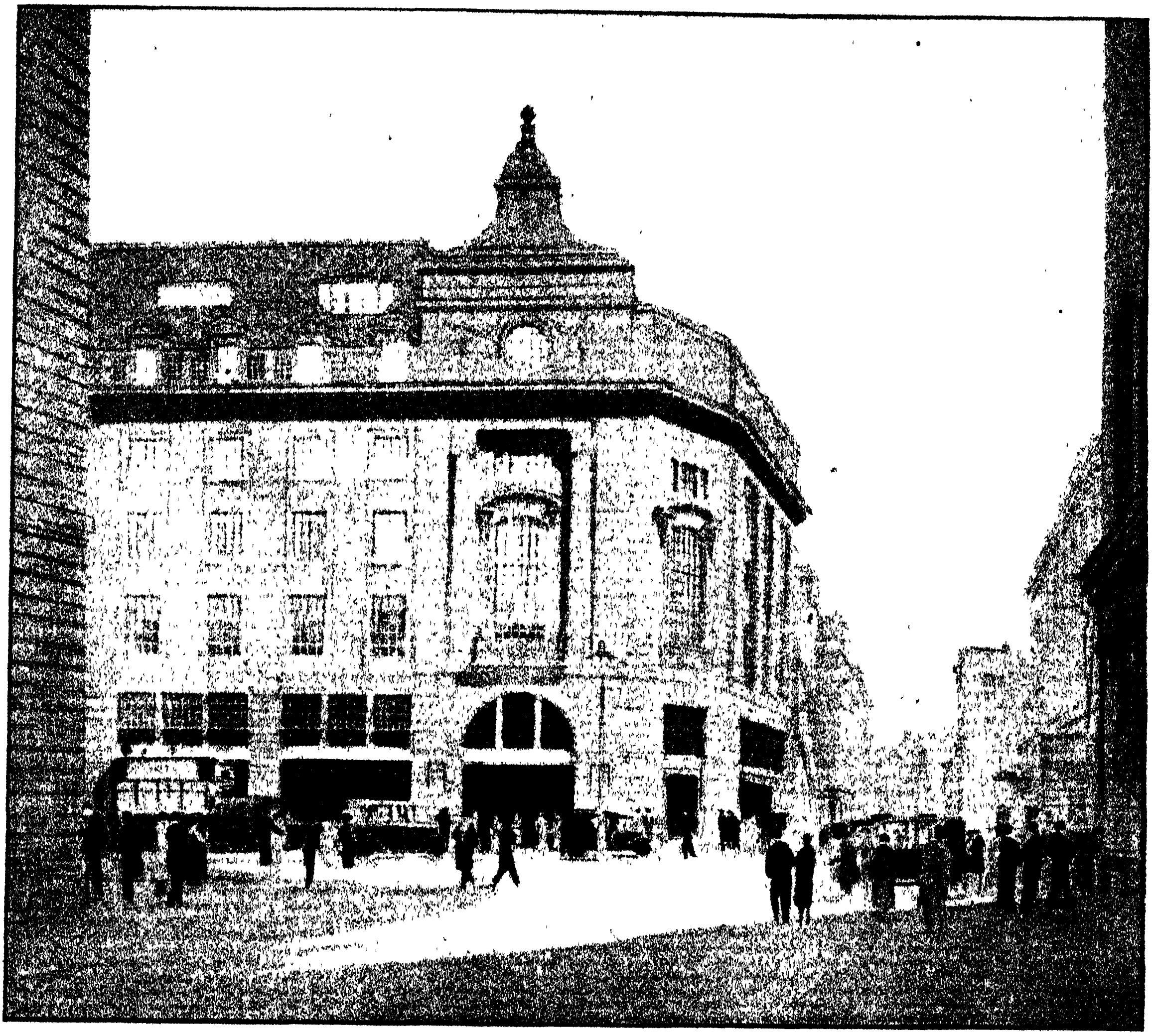


Fig. 68. A Modern Shop in Regent Street, London

Line and Colour. Fig. 69 shows a bank interior. It is reproduced from a large drawing

about 40 in. by 30 in. in strong colour. The detail was of some importance, and the selection of this type of view is difficult. Composition *must* be good to prevent distortion of detail which is close to spectator. Note the strength of ground detail to emphasize lightness of fabric, and the centre of interest which is so placed to attract the eye away from overhead lines. Pencil work in this drawing was very strong and Ordnance map to a convenient scale, and put the squares into perspective, drawing in the main plan features of the country freehand; this is indicated in scroll at left bottom corner of drawing. Then square up the plan of scheme in a similar way, subdividing the original squares as necessary, and drawing in the design as solids or blocks of building. Having decided on the view, complete by detailing blocks to scheme.

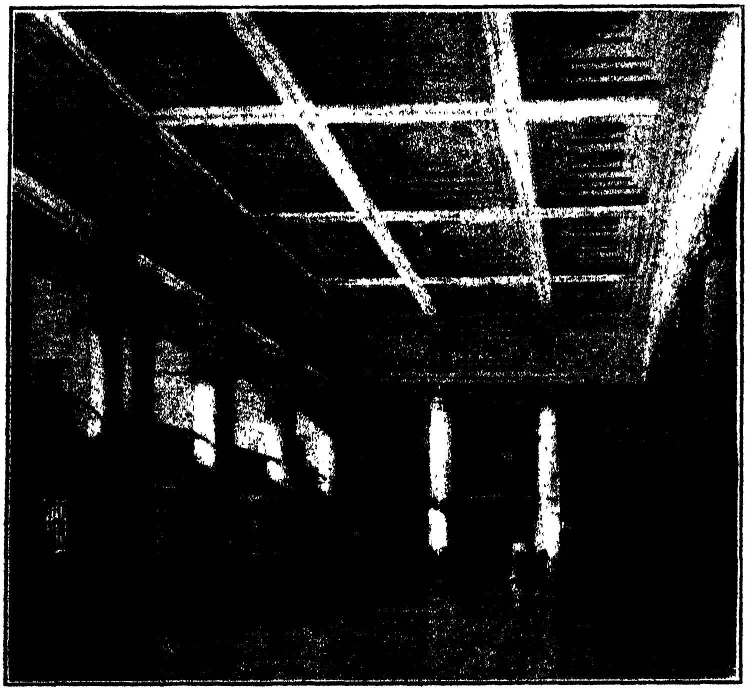


FIG. 69. A BANK INTERIOR

cleanly drawn to make washes of shadow and texture appear as transparent as possible. When making these views, many trials of the effect are advisable on rough paper at actual size, to allow of clean rendering in a decisive manner.

Bird's-eye View, Pen Line. A line perspective of Bushey Schools is shown in Fig. 70, and is a competition perspective, where a "bird's-eye" line drawing was imperative. The only difference in a bird's-eye view is that the H.L. is chosen at sufficient height to explain the planning of the scheme. The advantages are apparent to the assessor, but the draughtsman finds it necessary to have a fund of knowledge of the roofing of the scheme, and the general aspect of the surrounding country. For such drawings it is sometimes easier to square up an

Line drawings are laborious but fascinating, and must be drawn and selected most carefully. Simplification is necessary, for the scale and surroundings should be added only to emphasize the disposition of the scheme.

Reference should be continually made to good drawings which frequently appear in the architectural magazines, and much information can be gathered from them both in composition and technique. Actual drawings, when seen at the Royal Academy or other exhibitions, will explain many points which are difficult to understand; but it must be realized that, while it is easy to set up a simple scheme in perspective, the only way to master good execution is by continual observation and sketching of effects, the practice obtained from all sorts of rendering, and a thorough knowledge of architectural work.

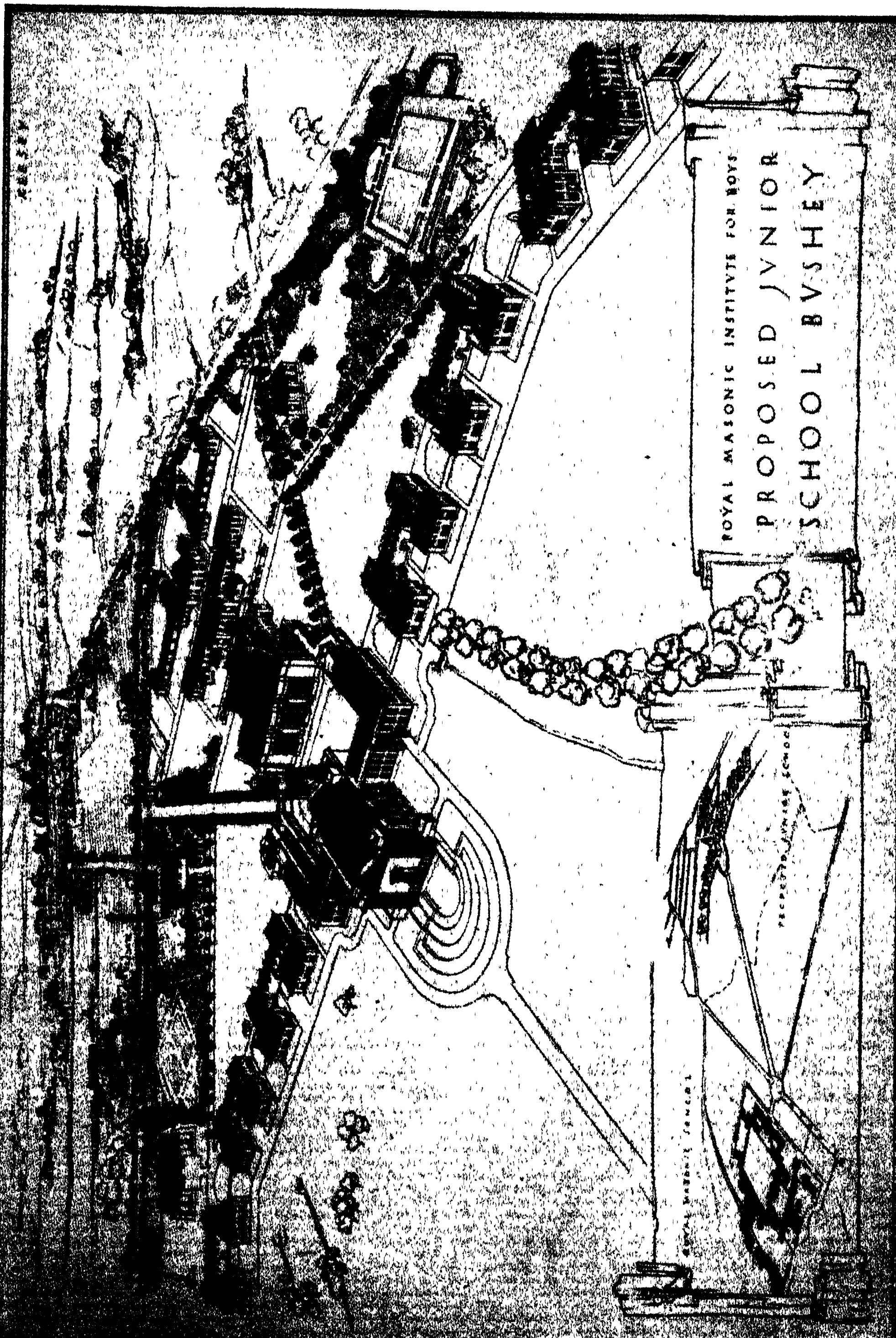


FIG. 70. BIRD'S-EYE VIEW IN PEN LINE

Chapter VII—MAKING AN ARCHITECTURAL PERSPECTIVE

THE working examples of perspective in the preceding chapter demonstrate the task of the perspective draughtsman and introduce the student to some of the decisions which do much to determine the final form of the drawings. By studying them, and by experimenting himself, he will become aware of the gap which exists between them and the designers' drawings from which they are derived, and he will also form some ideas about the steps taken in bridging it. This chapter is intended to assist him in clarifying these ideas by means of a general survey of the considerations involved in making architectural perspectives.

Architectural perspectives are explanatory drawings in the form of pictures intended to describe designs to the layman. This is their purpose, and, if the purpose is to be fulfilled, the drawings must be both visually accurate and generally intelligible. Accuracy is achieved by the application of the science of perspective and the results are rendered intelligible by the adoption of a degree of pictorial realism. The need for accuracy precludes any wilful distortion of form and the desire for realism limits the degree of symbolism to that which is generally recognizable.

Architectural perspectives, then, are essentially representational drawings, having problems and aims akin to many of those contained in any topographical drawing; but there is one essential difference. With the topographical drawing, the subject already exists: it can be studied visually and the effects of light and shade, colour, and texture can be recorded as they are seen. The subject of the architectural perspective, however, has no concrete existence, so the whole of these effects must be built up synthetically by the draughtsman from his experience of similar subjects, and from such notes for reference as he may have.

The beginner has his knowledge of the geometry of shades and shadows, together with some sketching experience, as a nucleus for what is required here, but he must be prepared to extend this by further sketching on the one hand and by collecting illustrations for reference on the other.

SKETCHING. Sketching, for the perspective draughtsman, is a means to a particular end, necessitating the production of accurate studies, made with careful regard to form and tone and colour values. The drawing reproduced in Fig. 90 is a good example of the kind of study required, and other examples of similar value can be found among the work of the topographical painters, etchers, and engravers of all periods.

The perspective draughtsman makes such studies to assist him in memorizing the appearance of things, so it is especially important for him to look before drawing and to draw only that which he can see. The architect tends to fail here, for knowing buildings as he does, he too often draws what he knows to be there, rather than what he can see: he thus loses the habit of looking; so, while his knowledge is an asset when making a perspective drawing, it constitutes a danger to be guarded against when making a study. The beginner, especially if he be trained as an architect, will do well to watch for this failing, as well as for the tricks and mannerisms it engenders, and to avoid them by concentrating on the production of full and accurate visual studies, unhampered by too much regard for conscious picture making.

The camera, if used in conjunction with drawing, can add to the value of these studies, and photographs, if taken from the same view-points as those from which the studies are made, provide interesting comparisons as well as checks on forms and tones. They may also add something to the information already gained, especially in regard to moving objects and reflections in glass and water, all of which are difficult to observe accurately.

COLLECTING ILLUSTRATIONS. Even the best memory requires prompting, so most draughtsmen amass a collection of miscellaneous illustrations to which they may turn when in need of specific information. Since the time and trouble of making such a collection systematically is amply repaid by the ready reference it affords, the proceeding is recommended as one which is worth while, and some suggestions as to its contents may be of assistance.

It should contain, first of all, reproductions

PERSPECTIVE IN COLOUR

of paintings, drawings, and etchings of buildings, and also photographs of buildings. Among the reproductions should be examples of topographical work, as well as architectural perspectives, and the work of such men as Canaletto, Guardi, Paul Sandby, Thomas Malton Junior, T. Shotter Boys and F. L. Griggs should be included. Some reproductions of the work of these men are obtainable in postcard form from the museums, so the cost of making a beginning need not be great.

The photographs to be included should be chosen for their value as records of effects of light and shade, especially in regard to these effects on windows, because these often present difficult problems to the perspective draughtsman.

Other elements recurring in architectural perspectives, and about which the draughtsman must be informed, are people and animals, vehicles, flowers, trees, and furniture. Useful examples of the first three can be found by hunting through magazines and daily papers, not forgetting the advertisement sections, while a seedsman's catalogue affords some useful reference on flowers. Good examples of trees, on the other hand, are not so easily found at random, so the buying of one of the several small books on them is recommended.

It will be noted that all these elements are of known size, and they are used, almost unconsciously, as units for measurement when they are included in drawings. They must, therefore be drawn "to scale" in perspective, and this procedure is greatly facilitated by the addition to the illustrations of such main dimensions as are not already known.

Beginning a Drawing

A perspective originates from the designer's drawings. These are generally in the form of plans, sections and elevations, and some architectural experience is required to visualize the subject in three dimensions from them. They form the major part of the information required by the draughtsman, but they seldom complete it, for an exterior must be shown in its surroundings, and an interior must appear as if inhabited.

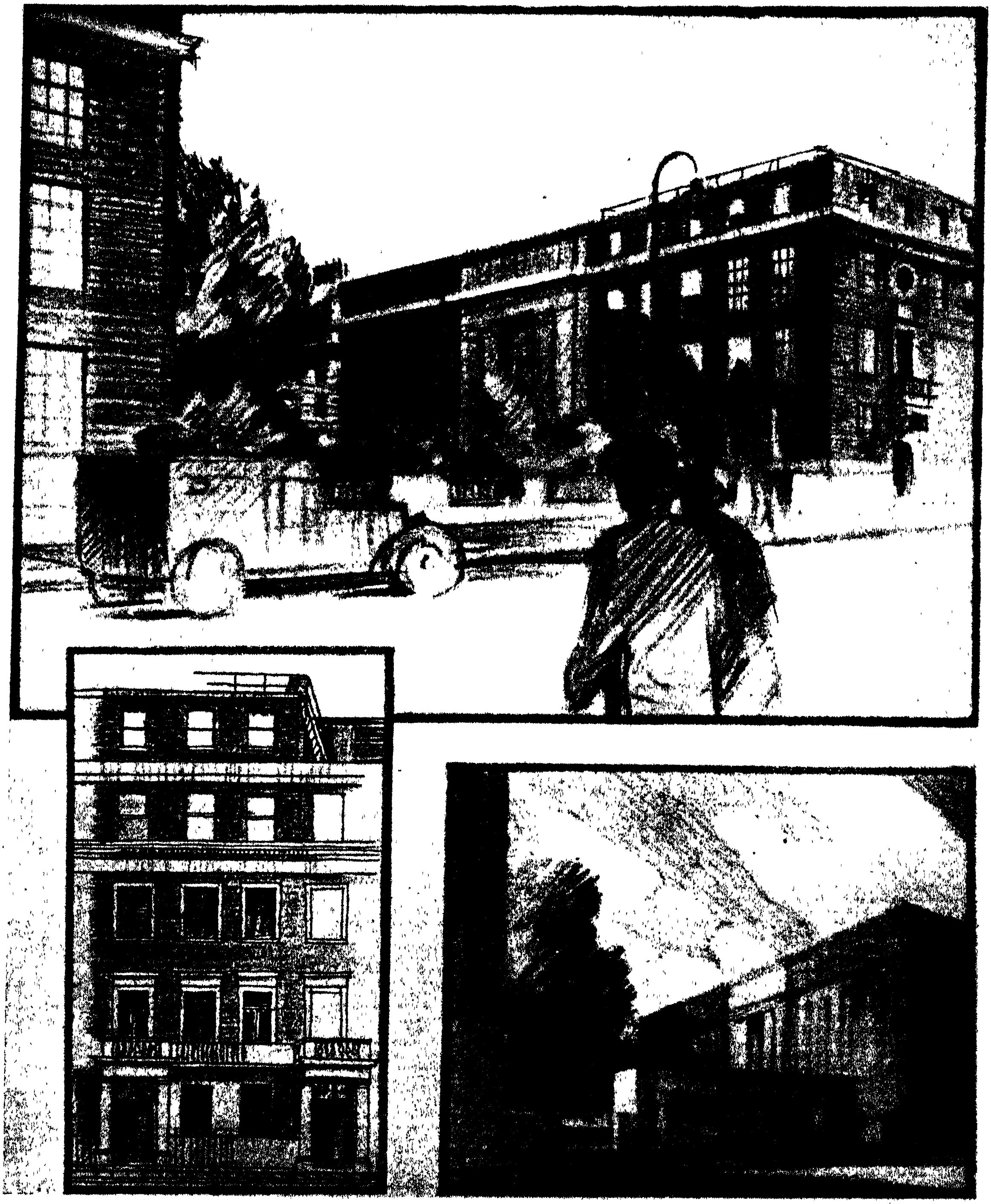
Exteriors. The surroundings of an exterior can usually be studied by visiting the site, and this should be made the rule whenever possible; general character, as well as form, is then observed and transmitted to the final drawing, giving it an air of authenticity, which it may otherwise lack. The drawing reproduced in Fig. 68 has so benefited: the "atmosphere" of Regent Street has been captured here, and its character is emphasized by the inclusion of appropriate vehicles and groups of figures, all indicative of first-hand observation.

The notes made on a site visit vary with individual needs, but generally they should include one sketch from a possible view-point recording the general effects, and this should be amplified by additional dimensioned notes of any adjacent building, or buildings or objects sufficiently near to the site to require accurate setting-up. Notes of road and pavement widths and the positions and sizes of any features of lay-out, should also be included. Some useful lateral dimensions can sometimes be obtained from Ordnance Maps, especially for bird's-eye perspectives, so these should be consulted whenever they are available.

A general sketch of the kind referred to and relating to the colour plate facing this page is reproduced in Fig. 71, and one of a number of notes accompanying it, in Fig. 72. In this instance the lateral dimensions were obtainable from the designer's drawings and from the Ordnance Map, so they were not recorded on the notes.

On those occasions when site visits are impracticable the draughtsman is dependent on his experience of comparable sites to assist him in developing settings from such information as may be available. This will vary in extent with the occasion, but the more varied the draughtsman's experience the more credible is the setting likely to be. Hence the rule of site visits whenever possible, since these, in addition to providing information in particular instances, are indispensable as a means of training.

Interiors. A perspective drawing of an interior provides a different problem, for there are no surroundings to be visited for information, and the picture must be built up within the designer's shell by placing within it those elements which help to establish its character and emphasize its function. A background of general knowledge concerning interiors, and a particular knowledge of furniture and furnishings is required to do this successfully: for the additions to the shell must be appropriate and in harmony with one another, and they must be placed as if the room were "lived in." Much information can be obtained from the many books and periodicals on interior decoration and furniture, and some of these are indispensable



FIGS. 71-72-73

for reference, but this information should be supplemented by visits to museums and showrooms for first-hand experience of detail and texture. All kinds of interiors, including good film and stage sets, should also be studied, both in regard to general character and lighting.

The selection of the elements to be included in an interior is the equivalent of the site visit to an exterior. Very little may be required, as in Fig. 69, where suitable figures appropriately placed have sufficed, or it may be that complete furnishings and even architectural details must be added, as in Fig. 74. In every case, however, the draughtsman should decide what is to be included, and select sufficient illustrations for reference before he begins setting-up; for this step will save him much tentative fumbling at a later stage by ensuring that he knows what he is about to draw.

Composition. Some instinct for pictorial composition, such as can only be acquired by analysing examples and by practice, is essential to success in this task, and the brief reference included here should be regarded only as an introduction to study of this kind.

Composition consists of developing the raw material, provided by a first impression of the subject as seen from an approximate view-point, into a unified and balanced design, about which the eye will move on a controlled path. This involves adjusting the positions, shapes and weights of the "quantities" contained in the first impression. These are the various areas which make up the picture, and they may be shapes enclosed by lines, or areas of tone, or areas of colour, according to the type of drawing.

The proportion of quantities must be arranged so as to avoid equalities of interest between them, for if equal interests are permitted to occur, attention wavers between them, and the design is not seen as a whole. This fact may be demonstrated by drawing two similar rectangles, and dividing the one into two *equal* areas of contrasting tone and the other into two *unequal* areas of contrasting tone. On examination it will be found that the first rectangle is not seen as a whole, for interest is equally divided between the two parts; the second rectangle, however, is more satisfactory, for one part is accepted as a subsidiary of the other, and the two parts together as a related whole.

The shapes and proportions of quantities must be designed to combine in a balanced pattern. Since the quantities in architectural perspectives are derived from buildings and their surroundings, all of which must be represented accurately, the kind of pattern made by these must be considered when choosing a view-point; for the proportions and shapes of objects, and therefore the quantities, are determined by it.

Quantities are combined to represent objects in space, and objects, having the quality of weight, must be balanced, one against another,

FIG 74

to ensure an effect of stability. The simplest example of balance is seen in a symmetrical arrangement, but, as symmetrical arrangements are rare in architectural perspectives, balance is usually contrived by adjusting dissimilar weights about a focal point, rather as dissimilar weights at each end of a beam are balanced by discovering the point of balance.

Such weights in a composition must be arranged so that the focal point is comfortably within the picture. This depends, to a great extent, upon the view-point chosen; for many of the weights in architectural perspectives are made up of objects whose forms, and relationships to one another, are pre-determined, but whose compositions change with each change in view-point. The possibilities of balance in a composition must be considered, therefore, when choosing a view-point, as well as the kind of pattern made by the quantities.

In compositions in tone the balance of weights is affected by the relative tone values of the objects; for generally the darker these are the heavier do the objects appear to be. The possible effects of lighting should be considered, therefore, when arranging the weights in such compositions.

In any balanced arrangement the eye moves from weight to weight when comparing them, and these can be so designed that it moves

from one to another in sequence, so following a prescribed path; for weights in a composition are generally built up of objects in different planes, and the eye tends to compare such weights, object by object, beginning with those which are nearest to it. In a simply balanced arrangement, for example, the weight, say, on the left of a centre of interest may consist of an object in the middle foreground combined with one in the distance, while that on the right may consist of an object in the immediate foreground together with one in the middle distance. In such an arrangement the eye tends to travel from the object in the immediate foreground (on the right) to the one in the middle foreground (on the left), back to the one in the middle distance (on the right), and then back again to the distant object (on the left).

It follows a path prescribed by an arrangement of objects, some of which attract more than others by reason of their positions in space.

The path of the eye about a composition can thus be controlled by the arrangement of the objects in space. Its design, therefore, influences the design of the various weights. It also influences the design of the pattern; for, since the path is meant to be followed, its course should be marked by the directions of some of the lines in the pattern, and, in tone arrangements, by the placing of the lighter tones.

To appreciate these various qualities of composition the student must examine examples. If he perseveres, he will find that he is gradually becoming aware of good distribution, and nice contrasts in pattern; of varieties and subtleties in balance; and of rhythm in the movement of the eye about a well-designed composition. He will find, also, that he is acquiring that instinct for composition which is essential to him.

The following are brief observations on a few of the illustrations in this section, made with the object of drawing attention to some of their qualities as compositions. The Roman composition, Fig. 86, shows an arrangement of architectural elements wherein any precise statement of their positions in depth is evaded by drawing them in elevation. The horizontal planes are thus left unexposed, and any impression of depth is contrived by contrasting the sizes of objects in different planes, such as the vase in the foreground and the dome in the background, and this impression is reinforced by differences of tone.

The pattern is composed of light-tones and half-tones interlaced with dark-tone, and the quantities are such that the lighter tones predominate. The groups of objects are so arranged that there is apparently more weight on the right hand side than on the left, and this difference is counteracted by placing the focal point consisting of the dome in the background, rather nearer to the heavier side, so as to balance the weights about it.

The differences between composition in elevation and composition in perspective may be more appreciated if this example is compared with the perspective interior illustrated in Fig. 95. Here, the horizontal surfaces of ceiling and floor by their exposure disclose the exact relationship of the elements to one another in space; any arbitrary adjustment of size, in the interests of balances, in any one of them will disturb their relationships by creating an obvious disparity of scale. And, since the sizes of objects, and their relationships, are determined by the view-point, changes in them can be brought about only by changing the position of the eye. Apart from the discipline imposed by the adoption of perspective, the considerations of composition in this example are not dissimilar from those in the former one.

The drawing reproduced in Fig. 96 also should be referred to, not only because the weights are well-balanced about a focal point formed by the view between the two buildings, but because it affords a good example of contrasted tone. The darks in it are excellently regulated in quantity, and are well distributed about the focal point, both in regard to minor contrasts, and in regard to their values in relation to the surfaces upon which they are placed.

The colour plate facing page 1257 affords an example in colour as well as tone. The colour pattern is based upon the distribution of the warm colours of the brickwork and the somewhat cooler colours of the sky, the trees, and the foreground. The forms in the design are, for the most part, horizontal in direction, and contrasts to them are afforded by the vertical shapes of the wall on the left, the recessed portico of the building on the right, and the lamp standard. Smaller contrasts, both of tone and colour, are contrived around the focal point, such as the dark of the gate, the green of the garden, and the dark tones of the shop window, while the light wall of the building on the right is enlivened by the dark notes of the open windows and the contrasting green of the window frames.

Composition Studies. In practice, the process

of developing a composition involves the making of a series of studies, beginning with the raw material and continuing until the extent, form, and tone of the intended picture are generally determined.

The first attempt on paper is seldom more than a literal transcript of the forms to be included, as seen from an approximate view-point; but it discloses the descriptive and pictorial possibilities of the arrangement, and so enables the draughtsman to assess them in relation to the view-point.

The view-point is the key to the arrangement, and to any subsequent adjustment of it; so much of the quality of the finished picture depends upon the aptness of the position finally selected. The particular conditions influencing the choice of its position vary with each circumstance, but there are some facts which govern the choice generally, and which may, therefore, be stated with advantage.

The nearness of a view-point is limited by the angle of vision, which operates vertically as well as horizontally. In exterior views, apart from "bird's-eye" ones, it will be found that a more "characteristic" picture is obtained from a view-point approximating to one which could be occupied in reality. For example, if a building is situated in a street, a more convincing result is obtained by adopting a view-point which is either apparently within the width of the street, or located in an adjoining building from which the subject might be seen. In interior views, because of the limits imposed by the angle of vision, it is common practice to place the view-point outside the limits of the walls, and to regard the interior as a stage set, with the fourth wall removed. A view-point from which the sides of the building are seen at 45° to the central visual ray, is generally avoided, because the two faces of the building are seen from it to equal advantage, and therefore tend to be of equal interest. A low view-point and sharply vanishing lines may create a more dramatic view, and suggest greater bulk, than a high view-point. An atmosphere of repose is assisted by avoiding such a view-point.

The view-point of a composition in tone or colour must be studied in conjunction with the lighting; for it will be remembered that lighting, in affecting tone, affects balance. Its direction in most compositions can be changed sufficiently to make considerable differences, but such changes should be limited to those which can take place on the given site, otherwise the picture may be quite misleading. In the colour plate, for example, the whole of the main frontage faces north, a fact which it would have been dangerous to ignore. Within these limits lighting may also be adjusted to reinforce the atmosphere of a composition. It may, perhaps, be arranged to make a vigorous tone pattern with sharp diagonal shadows, and enhance dramatic quality, or to bathe the subject in soft even light and contribute to repose, and so on. Excellent examples of this use of lighting may be found among the architectural engravings of Piranesi, who relied on the expedient freely in the creation of dramatic effects.

When making composition studies, all the considerations of composition must be thought of together, for they are all interdependent. If the work of development is to proceed smoothly, therefore, a knowledge of them, together with some flexibility of mind regarding them, must be acquired. This must be accompanied by a method of working which will enable the numerous changes to be made easily during the course of development. Small, free sketches, measuring not more than a few inches in either direction, afford the best means here. These should be made with a soft pencil, or crayon, on tracing paper, one drawing being made over another as alterations are required instead of rubbing out and redrawing each time. This procedure enables the development to be reviewed at any time during its course, and provides an instructive comparison between the first attempt and the final composition when completed. Working on tracing paper has one further advantage; it enables the composition to be seen "in reverse" merely by turning the sketch over, a proceeding which often assists the draughtsman by providing an entirely fresh view of it.

The little drawing, Fig. 73, is one of a series of such sketches, made as a preliminary to the perspective illustrated in the coloured plate facing page 1257. It may serve as an example, in so far as it contains the essentials of the intended composition in a simplified form, and has served as the basis of the final perspective.

Setting-up

The principles of perspective as explained in Chapter VI must now be used to create the required drawing. The first process, known as "setting-up," is a mechanical one which translates the draughtsman's preliminary sketch into the full size drawing of the composition.

Sequence. Time is saved, and inaccuracy is avoided, by ordering the stages of this process in sequence, and by completing the preliminary ones carefully before passing on to the final drawing. The stages, as they occur, consist of

(*a*) preparing the plan (from which the perspective is projected);

(*b*) discovering the view-point (approximating to that of the composition study);

(*c*) setting the plan in relation to the view-point;

(*d*) establishing the picture-plane;

(*e*) finding the vanishing-points and projecting the visual rays;

(*f*) arranging the board for the convenient projection of the image, and, finally,

(*g*) projecting the image.

Much of the general procedure has already been explained in the preceding chapter, so in describing the stages now, reference is limited to such items of sequence and procedure as may assist the beginner in establishing his own method of working.

(*a*) PLAN FOR PROJECTION. On nearly every occasion, the designer's drawings must be adapted for this purpose. Many draughtsmen choose to combine all the required information concerning the plan forms of a building, at all the different levels, on one plan; for, by so doing, all the visual rays can be projected at one time, and on one drawing; this can then be set, and need not be moved until the projection of the image is completed. Since a careful perusal of the designer's drawings is necessary to its preparation, the draughtsman is enabled while acquainting himself with the intricacies of the design, to detect and correct any discrepancies in them before the work of projection is begun. Such composite plans are seldom so complicated that they are difficult to read, and on the few occasions when they are so, they may be clarified by using inks of different colours to denote changes of plane, and other variations, at the different levels.

The composite plan prepared for the perspective reproduced in the colour plate facing page 1257 may be seen on the inset Sheet One. In this case, the designer's drawings consisted of sets of eighth-inch scale drawings of the buildings on the right and left of the centre, together with quarter-inch scale drawings of the little book shop between them. These were combined into the one-eighth inch scale composite plan, as shown, for the purpose of the projection.

(*b*) DISCOVERING THE VIEW-POINT OR S.P. The view has already been decided upon, and is recorded in the final Composition Study, Fig. 73; but the position of the actual view-point on the plan, now referred to as the Station Point (S.P.), from which this view is obtained, has yet to be discovered. This need not be a process of trial and error only, and a position which approximates to it very closely may be deduced from the composition study by applying perspective principles "in reverse," as illustrated in Fig. 75.

This figure shows, in the sketch, a tracing of the main lines of the composition study with sufficient space around it to accommodate a construction, whose evolution is now to be described. Assume that the sketch is so mounted but with no construction lines upon it, and begin by "sighting" the eye-level, or horizon line, as it appears in the sketch, and marking it by means of a horizontal line. Extend this line sufficiently, to the right and to the left, to accommodate the vanishing-points, when found. This is the line *HL* in the figure. Extend the vanishing lines of the buildings in the sketch until they cut *HL* at points which are the vanishing-points *VP*.1 and *VP*.2. Assume that the centre of vision is on the centre line of the picture and mark its position as *C V*.

Now assume that *HL* represents the picture-plane on plan, with the positions of *VP*.1, *VP*.2, and *C V* established upon it, and, through *C V*, draw the central visual ray (C.V.R.) in plan. The station point (S.P.), is located somewhere on this line, and its exact position may be discovered by drawing lines parallel to the plan *back* from *VP*.1 and *VP*.2 until they intersect with C.V.R. Now their angle to one another must be the same as the angle formed by the front and side planes of the buildings on plan. And from the designer's drawings, this angle is known to be a right-angle; so, if a right-angled triangle be drawn, having the intersection of the right-angle on the line C.V.R., and having the line *VP*.1, *VP*.2 as its hypotenuse, the position of S.P. will be determined by the position of the intersection of the right-angle on C.V.R. To set out this right-angle, describe a semi-circle with the line *VP*.1, *VP*.2, as its diameter; the point at which this semi-circle cuts C.V.R. is S.P., and the angle *VP*.1, S.P., *VP*.2, is the desired right-angle. S.P., then, is the view-point, and the angle at which the buildings are turned to the C.V.R. is the same as the direction of the triangle. The angle of vision can now be

discovered also, for S.P. is known and the extent of the picture has already been determined in the sketch; so, if the points at which the *HL* cuts the edges of the picture are connected to S.P., the angle so formed is the angle of vision. S.P. on the composite plan is not found by scaled dimensions, but by means of the two angles already discovered. These two angles are (1) the angle at which the building is turned to the C.V.R., and (2) the angle of vision. With these,

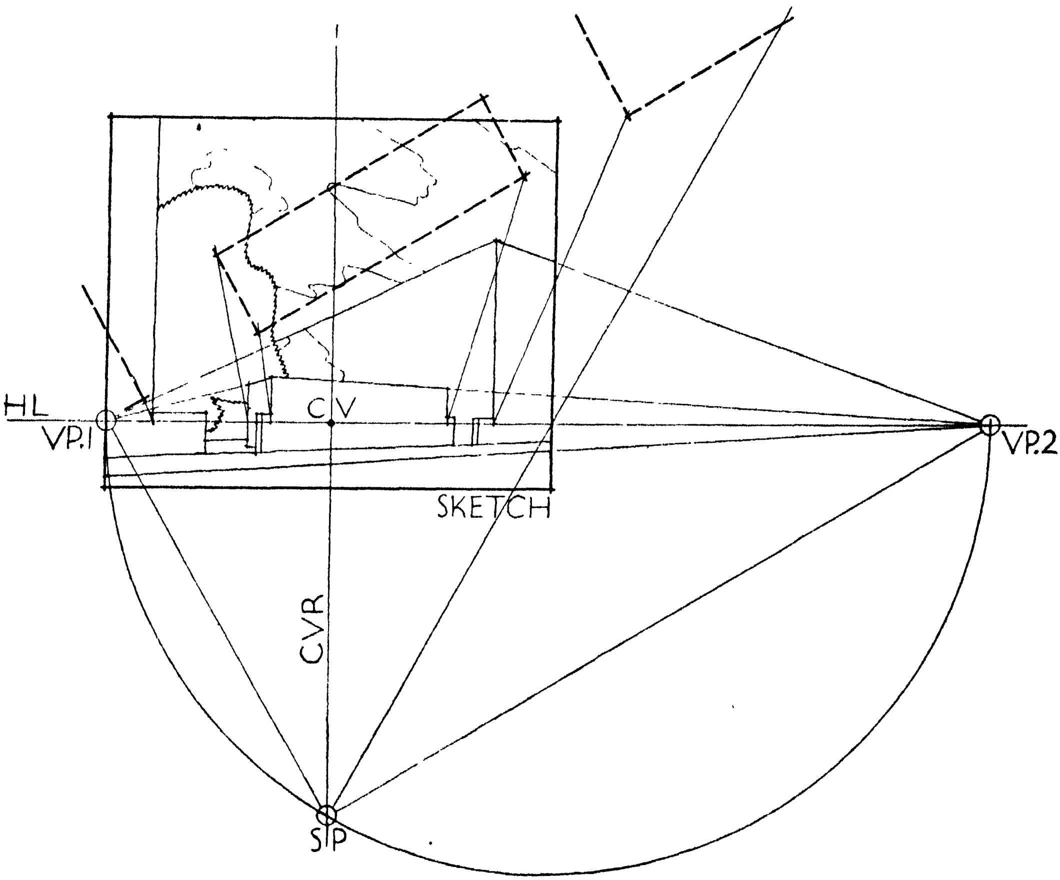


FIG. 75

and with the limits of the picture already decided upon, the position of the S.P. on the composite plan is found by a simple process which can be followed by referring to inset Sheet One.

The main plan forms can now be projected by drawing the visual rays from S.P., and setting the forms within them, as shown by the dotted lines in the figure, and they may be used to check the plan proportions of the sketch against those of the designer's drawings.

This method of discovering the relationship between view-point and subject may also be applied to the majority of photographs.

(*c*) SETTING THE PLAN. The information obtained from the composition study can now be applied to the composite plan already prepared; but, since the scales of the two drawings are seldom easy to relate, the position of the

First of all, mark on the plan the extent of the buildings to be included within the angle of vision, and then set the plan on the drawing board so that its angle to the ruling edge of the T-square is the same as the angle of the building to the picture plane. Now, with the marks on plan to determine its limits, draw the angle of vision *back* from the plan until the two rays intersect. The point of intersection is the

required S.P., and the line which bisects the angle is the C.V.R.

(*d*) THE PICTURE PLANE. Having established the C.V.R., the working position of the picture plane, which must always be at right angles to it, can now be established. In practice, its distance from S.P. is governed by the size of the image required; for the size of the image increases as the distance from S.P. increases, and the plane can be placed either before, behind, or through the subject at will. This is general practice in architectural perspective, and images projected on to planes in these different positions vary only in size: in all other respects they are exactly alike. This point is emphasized because there are some theorists who assert that there can be only one position for the picture plane, for they insist upon its physical existence as the "window" upon which the forms can be traced when seen through it. The position of this particular plane can be found on plan, for its distance from S.P. is dictated by the depth of the foreground which is limited by the angle of vision operating vertically.

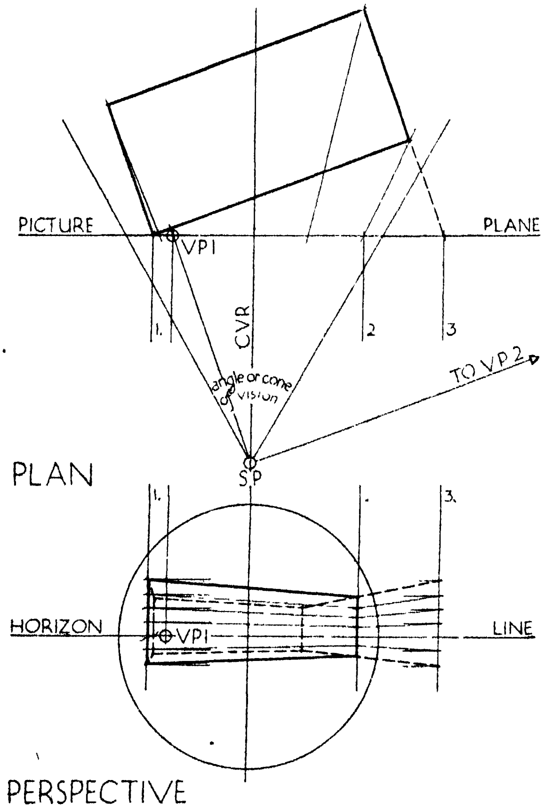


FIG. 76

If the image on such a plane appeared more true than on any other, such a practice might be justified, but this is not so. Also, the only way to change the size of such an image (or drawing) is to change the scale of the plan or to enlarge it geometrically. Such cumbersome methods become an impossible handicap in practice; they confer no benefits and are therefore disregarded.

In the inset Sheet One, both "theoretical" and "practical" planes are shown, and *PP.*1 is the actual plan position of the "window," while *PP.*2 is the plane upon which the image seen in inset Sheet Two is projected.

(*e*) VANISHING POINTS. With the picture plane determined, vanishing points can be found and visual rays projected, while the height lines are also fixed by its position. Methods have already been detailed in Chapter VI, and only the practical problem of working *VP's* within a reasonable space need to be dealt with here. Since one, at least, of these *VP's* is frequently "off the board," other expedients adopted for reaching them need to be explained. The perspective grid is one of the expedients useful in making sketch perspectives. This is shown in Fig. 76, where a rectangular solid is set at such an angle to C.V.R. that only *VP.*1 can be discovered by direct projection, and where lines vanishing to *VP.*2 are to be drawn by means of a grid of guide lines only. The grid is drawn by using *VP.*1 only, and a beginning is made by establishing the horizon line, *HL*, and the height line, 1, and then drawing the plane on the left, which vanishes to *VP.*1. Its counterpart on the right is then drawn by first extending it to the picture plane to establish its height, 3, which at that point is the same as 1. Its position in perspective, and its length, are then determined by projecting the visual rays from the plan, 2. The plane, whose *VP* is *VP.*2, can then be drawn by connecting these two planes; its height is then conveniently subdivided to form the grid.

Fig. 77 shows a method of discovering vanishing points on plan "to scale," instead of to "full size," by drawing the distance from *PP* to *SP* to a reduced scale (quarter full size in the example), finding the distance from *C V* to *VP* to this scale, and afterwards translating it to full size.

The Centrolinead. For working to distant

vanishing points on detailed drawings a straight-edge is needed for all planes, and a "centrolinead" is almost indispensable. Fig. 78 shows an improvised one and also illustrates the

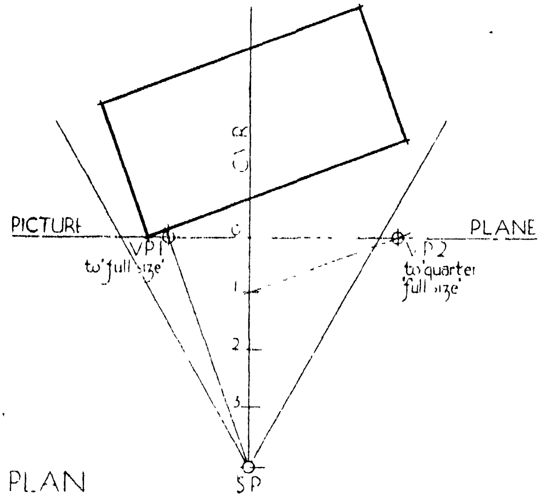


FIG. 77

principle upon which these instruments work. It consists of a straight-edge attached to a cardboard butt, the back of which is cut in the form of an arc having the *VP* as its centre, and which works against a corresponding fixed arc, so that the butt travels on the curve of the arc, with the straight-edge always pointing to the arc's centre, which is also the *VP*. To make it, the distance from *C V* to *VP* must be set out to full size on a wall or floor to strike the arc on the cardboard forming the butt. Before striking it the cardboard must be fixed in the same relative position to *C V* and *HL* as it will occupy on the drawing, and the straight-edge must be fixed to correspond with *HL*, all as shown in "A." The whole assembled for working is shown in "B." The centrolinead proper is an adjustable but expensive straight-edge device which performs the same function.

In addition to these aids to direct drawing, there is one further method of overcoming the practical difficulties of setting up a big drawing, and that is, by making a setting-up to a small scale first, and then having it enlarged photographically. The setting-up for this purpose is generally made on tracing paper, and is drawn with hard, firm lines. Enlargements of the desired size can be made from this on any one of a variety of papers, and they can be worked up in almost any medium. This method is especially useful for rapid work, where broad general effects are required. The work of enlargement is undertaken by most of the photo-printing firms.

(*f*) ARRANGING THE BOARD. Many hours of work, amounting perhaps to weeks of time, are devoted to sometimes setting up a big drawing, and even on the smaller drawings much of the total time spent is devoted to this process. It is important, therefore, to avoid unremunerative labour and unnecessary movement in carrying out the work, and both may be avoided, in part at least, by devoting some preliminary thought to the arrangement of the drawing board. One arrangement which works well in practice consists of setting the plan sheet at the top of the board so that the *PP* is parallel to the edge, and then setting the sheet, upon which the image is to be projected, beneath it so that the two can be directly related for working. Points on the *PP* can then be projected by means of a T-square working vertically across the board, and the need for transferring dimensions from one board to another, either by tick-strip or scale, is thus avoided. This arrangement may be envisaged by imagining inset Sheets One and Two set in these rela-

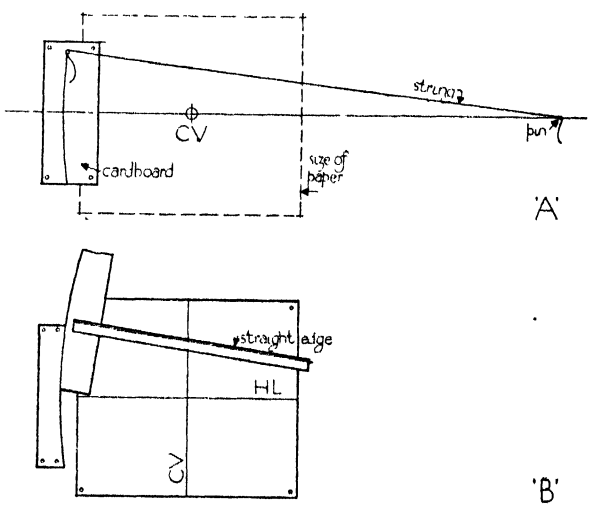


FIG. 78

tive positions with a T-square working vertically across Sheet One to the *PP* on Sheet Two. Repeated reference to other drawings may also be avoided by using vertical height strips. These are strips of paper, having the position

of the *HL* together with the vertical dimensions such as sills, window heads, copings and so on marked on them. The strips are temporarily pinned against the height lines on the image for the purpose of projection.

(*g*) PROJECTING THE IMAGE. The type of drawing made in this largely mechanical operation depends upon the part to be played by the actual pencil lines in the final result. They may not appear at all in a pen and ink drawing or a body-colour drawing; on the other hand, they may not only appear but may also contribute strongly by defining form and suggesting texture in a wash drawing. The quality of the drawing, therefore, must be adjusted to suit the desired result, but, whether the lines appear or not, it must be of such quality and completeness as will enable the rendering to be carried out without hesitation due to lack of detail. Too much, rather than too little, should be the rule, for lines can be suppressed more easily than they can be added, especially after the setting-up has been removed from the board for rendering. The setting-up in line for the colour plate facing page 1257 is reproduced in Fig. 79. Firm definition was required here as a basis for rendering, and it was also desired that some of the lines should be visible through the rendering to define detail and to give texture to the brickwork.

RENDERING

The term "rendering," when applied to architectural perspectives, is used to describe the work which follows the process of setting-up, and consists of developing the pictorial qualities and descriptive power of drawings by emphasizing line or adding tone or colour. Line drawings are simple statements of form in line only and are generally made for the purposes of economical reproduction. Tone, or monochrome drawings are fuller statements of form in which light and shade, texture and depth are expressed by means of varied tones. They may be executed in wash, charcoal, conté crayon, carbon pencil, pencil, or pen and ink, and they are used for both reproduction and exhibition purposes. Drawings in colour are full statements made in both tone and colour. They may be executed in transparent water colour or opaque colour, including pastel, and may be used for any purpose where first-hand inspection of them is possible, but as their tone values can be reproduced accurately only by somewhat expensive methods they are not suitable for reproduction in monochrome (one tone) only.

Choice of Medium. The type of drawing to be made, whether line, monochrome or colour, depends, of course, upon the purpose for which it is intended, but within certain limits there is more than one medium to choose from, and the final selection is regulated by the size and importance, the degree of detail and the range of tone, and perhaps colour, desired in the final production. The varieties of media in general use have already been mentioned, but some brief information regarding their ranges and application will help to guide the beginner in his selection for experiment.

PENCIL. Both slight impressions and highly detailed renderings can be produced with pencil. It can be handled either vigorously or delicately, and its flexibility can be extended by using pencils of different degrees of hardness, and papers of different grains and textures. Its range of tone is limited, however, for intense blacks cannot be obtained by means of it, and its effect becomes thin and sometimes laboured if applied to big surfaces, so its use is generally reserved for small and intimate drawings, intended for close inspection.

PEN. The pen is a difficult instrument to control if used freely and vigorously, and, when used in this way, repeated attempts are often necessary before the desired result is obtained. Because of the time and labour involved in making such attempts with an architectural perspective, most draughtsmen use the pen as an instrument either for simple delineation in line or for the building up of tones by a system of careful hatching, which can be controlled throughout the process of a drawing. A full range of tone can be obtained in this way, but, since each tone is contrived with separate, and often fine, pen lines, the process does not lend itself to the production of big drawings. Pen and ink perspectives are, therefore, generally small and carefully detailed studies.

"CHALK-LIKE" MEDIA. These all lend themselves to rapid working and to the production of big as well as small drawings. Carbon pencil is one of the most popular, for it can be used easily, both as a fine point on detailed renderings and as a broader surface in looser treatments. The French conté pencils can be similarly used, and as these are obtainable in a range of colours, colour effects can be achieved by means of them as well. Both carbon pencil and conté pencils afford a full range of tone, and their effects can be varied by the use of different papers, as with pencil, and also by the use of tinted papers.

Charcoal, generally used in its compressed form, is seen at its best when used for bold, free drawings. Detailed renderings can be made with it, however, but only by "smearing" the charcoal and working up the detail in a drawing with stump and eraser to a finish not unlike that obtained with wash. Pastel is another medium which is seen at its best when used boldly, and an expert can obtain full colour effects with it, but since it requires "painter-like" and confident handling of a kind only acquired by long practice in its use, examples are seldom seen.

WASH. Wash can be used freely and quickly to establish an impression, or it can be used to build up effects in considerable detail by successive applications and by sponging and erasing; it can be used for drawings of almost every size. It is thus extremely adaptable and is in consequence one of the media most generally used. Chinese ink, other soluble inks of various colours, process black, and water colour are used for monochrome drawings, while water colours, applied either as direct tints or over a monochrome rendering, are used for coloured drawings.

OPAQUE COLOUR. Transparent water colours with Chinese White added, poster colours, tempera, and oil colours, are media used for producing perspectives on those occasions when full, solid colour rather than tint, is desired. These all obliterate the ground, and the drawing over which they are worked, because they are opaque, so the setting-up becomes only a guide for the placing of colour, and can be simplified in consequence. With the exception of oil colour, closely controlled graduations of tone can be obtained only in these media by lengthy processes of stippling and hatching, so most of the perspectives produced with them are designed in flat, simple surfaces and are "poster-like" in appearance. With oil colour, on the other hand, effects of great subtlety and fine detail can be obtained by skilful handling, but its processes are slow and exacting; for these reasons perspective draughtsmen, with whom speed of execution is so often a factor, rarely use it.

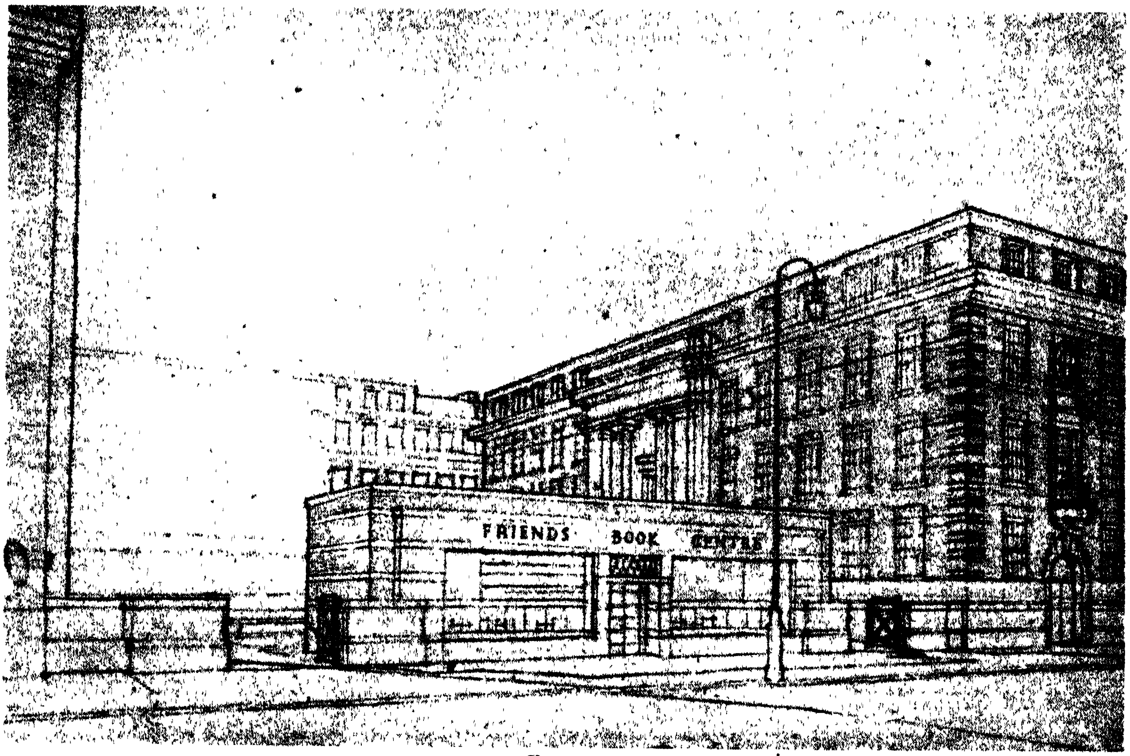


FIG. 79

Combinations of many of these methods such as pen and wash, charcoal and wash, carbon

pencil and wash, and carbon pencil and body colour, are generally accepted and frequently used.

Further reference to some of these media will be found in Chapter VIII, and some of the materials used are described in detail in Chapter I. These chapters, therefore, should be studied in conjunction with this section.

Tone Studies. The success of an architectural perspective, if executed in monochrome or colour, depends to no small extent upon its tone values, for it is by means of these that the modelling of the subject is established and the composition defined. Their general arrangement must be decided upon when the composition study, referred to earlier, is made, this being the "key" to the final drawing; in producing the final drawing, however, it becomes necessary to develop this arrangement in much greater detail in order to convey a full impression of the subject. An experienced draughtsman can develop his arrangement of tones on the final drawing, with only his composition study to guide him, because he has encountered similar problems many times before, but for the student, such a proceeding involves trouble, due to doubt and hesitation and frequent disappointment. An intermediate stage is therefore desirable between the composition study and the final drawing, in the form of a preliminary tone study carried out to the same size as the final drawing and developed in as much detail as may be necessary to enable the draughtsman to solve all the tone problems of his picture. A study of this kind can best be produced after the setting-up has been completed by working over it on tracing paper with compressed charcoal or carbon pencil, either of which can rapidly be smeared and erased to produce effects of tone. An example made by this method and used in the production of the colour plate is reproduced in Fig. 80.

Colour. An examination of architectural perspectives executed in colour suggests that most draughtsmen are agreed that a restrained use of colour is best suited to the task. Schemes of strongly contrasted colour certainly tend to detract from the detail of the subject, as they are seen primarily as colour patterns in which pattern becomes the major consideration; and the fact that it does so involves the draughtsman in difficulties, for many areas of colour in an architectural perspective cannot be adjusted to an unlimited extent to suit the needs of pattern making, since they represent objects or parts of them which must be presented factually. Strongly contrasted colour, therefore, is rarely used and the key most generally adopted is the comparatively low one of the nineteenth century topographical draughtsmen, examples of whose work it has already been suggested should be included in the collection for reference. An examination will show that many of these drawings were produced with a very limited palette and that as a result they are invariably unified and harmonious in colour. A palette can, in fact, be limited to three colours without sacrificing to any marked degree the illusion of colour in a final drawing if the three colours approximate to the primary colours red, yellow, and blue. These can be chosen from a range of from orange to brown for the red, from greenish yellow to orange for the yellow and from green-blue to purple for the blue. Three suitably chosen colours, one from each of these ranges, will suffice for most renderings, and if the three colours chosen are adhered to throughout any one rendering, it will be found that the task of unifying the colour in the final drawing becomes comparatively simple.

Tone values in a colour drawing demand special care, and values in the final drawing should be checked constantly against the tone study. Some draughtsmen prefer to build up a monochrome base on the final drawing itself, in which the main tone changes are established in order to safeguard themselves against error, and this method is recommended to the beginner, if for no other reason than that it enforces a consideration of tone as well as colour in the making of the drawing. The Colour Plate illustrates both the remarks on colour and this method of establishing tones, for in its production the palette was limited to three colours, except for one or two small details, and the drawing was completed on the monochrome base reproduced in Fig. 81.

Craftsmanship. The method of handling any medium is derived from the characteristics of the materials and tools used. Thus a pen drawing is built up of lines characteristic of the pen, a wash drawing of tints floated on characteristic of brush and fluid, and so on, each medium having its own characteristics, and also limitations. Good craftsmanship springs from a realization of these, so every student wishing to become a good craftsman must first learn to recognize those qualities in a work which are the result of a just handling of the medium. Both experiment and study are necessary here;

experiment with tools and materials, with the object of acquiring some feeling for their characteristics, and study of original work executed with them, with the object of noting the different effects obtained by the various methods of handling. A knowledge of the scope of each medium can thus be obtained, together with some ideas about usage.

It is possible to formulate a modest technique with this knowledge, limited, say, to simple systems of hatching in pen or pencil, or flat washes in water colour, which will yet be sufficiently extensive in its range to permit some experiments in rendering being made. When these are attempted they should be very simple to begin with, and of a kind that will enable the student to concentrate his attention as much upon his handling of the medium as upon the final result. Generally they should be limited to broad renderings of simple subjects in not more than three tones until some skill and confidence have been acquired.

METHOD IN APPLICATION. Rendering cannot be directed towards any particular end if it is allowed to proceed in a haphazard way, and only one or two experiments on the lines indicated above will suffice to show the need for a planned sequence of operations. The sequences used vary with individuals, but they all have the same aim; and that is, to develop a rendering in such a way that the parts of the picture may be judged in relation to one another and to the whole, at every stage of its execution. This is an aim which cannot be fulfilled by attempting to finish one part of the rendering before another is started, and experience will show that in order to fulfil it the whole rendering must be brought forward stage by stage, beginning with broad surfaces, and finishing with small details. One serviceable method, which permits of this, consists of developing the rendering tone by tone, beginning with the light ones and continuing until the darks are finally laid in. This sequence is suited to pencil, pen and ink, and wash.

FIG. 80. TONE STUDY

DEVELOPING A TECHNIQUE. A draughtsman's

technique is compounded of his manner of handling and method of working. It develops gradually in the course of his experience. The student, therefore, cannot expect to acquire a complete technique at once. He can, however, help himself in the building of one, when once he knows a little about his tools and materials and is aware of method, by studying the work of those draughtsmen whose productions afford evidence of direct handling and obvious planning. Such study is recommended, and, in the absence of any first-hand explanation or instruction, he is advised to begin it by making copies of a few examples of such work, not with the object of producing facsimiles by piecemeal methods, but with the object of discovering the sequence of operations employed by the original draughtsman, and of learning something of his methods of handling. The works of F. L. Griggs and the early water colours of John Sell Cotman are recommended for this purpose.

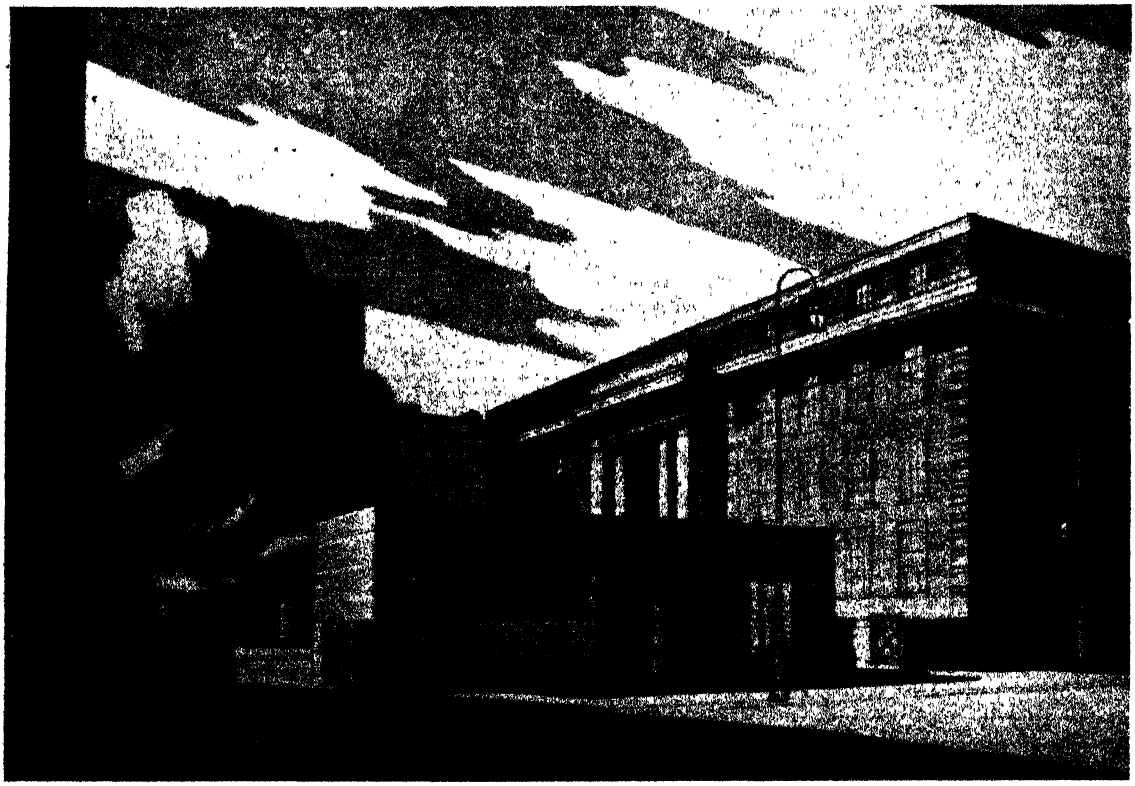
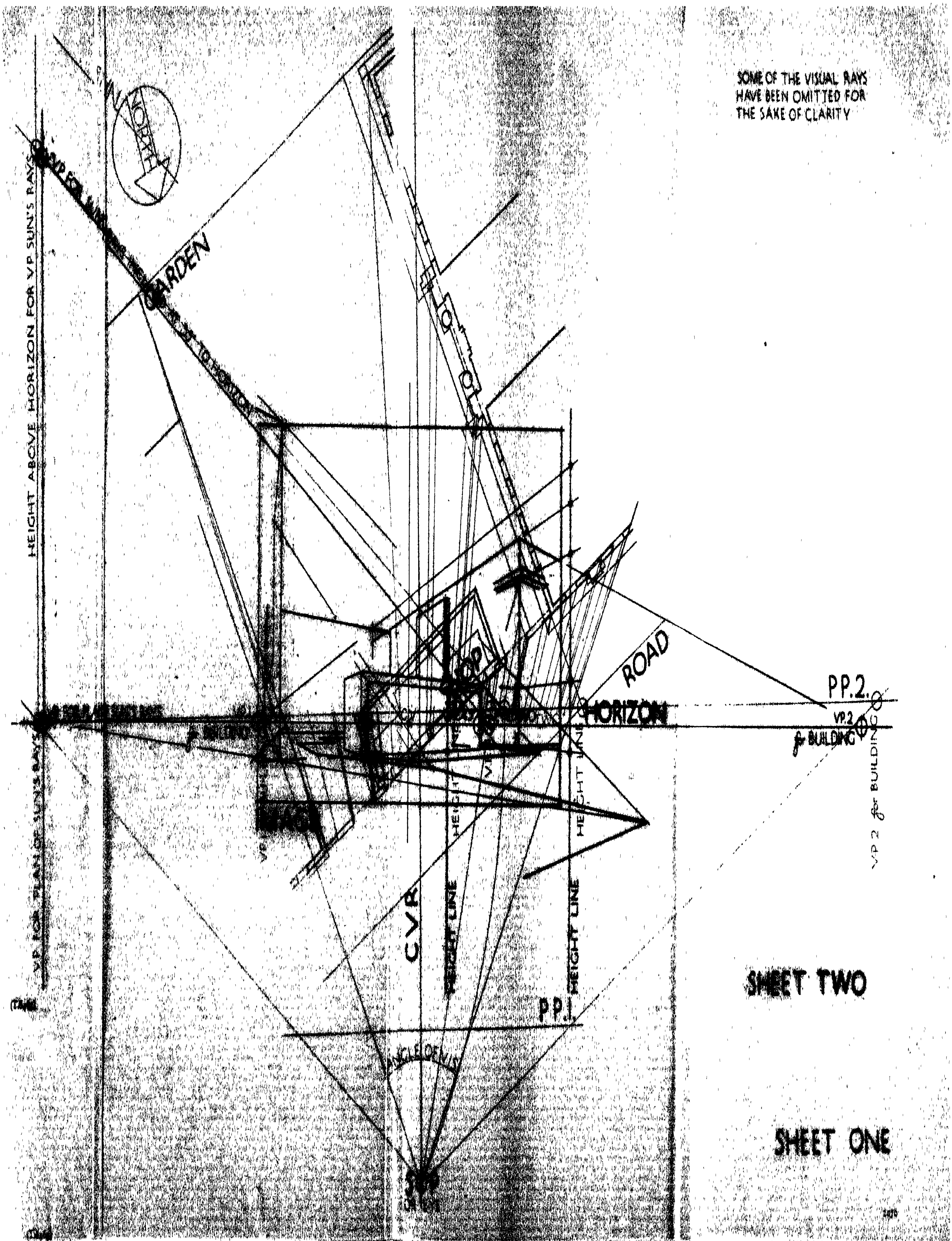


FIG. 81. MONOCHROME BASE

Such copying has only a limited use and it should be discontinued as soon as some insight into method and handling has been gained. From then on the student must rely on practice and self-criticism for his development. In this he should aim, for a time at least, at perfection of method rather than elaborate results, for without method each rendering tends to become an isolated experiment instead of a step in the development of a technique.


SOME OF THE VISUAL RAYS
HAVE BEEN OMITTED FOR
THE SAKE OF CLARITY
NORTH
GARDEN
HEIGHT ABOVE HORIZON FOR VP SUN'S RAYS
ROAD
HORIZON
PP.2.
VP.2
for BUILDING
VP 2 for BUILDING
HEIGHT LINE
HEIGHT LINE
CVR
P.P.I.
SHEET TWO
SHEET ONE

SOME OF THE VISUAL RAYS
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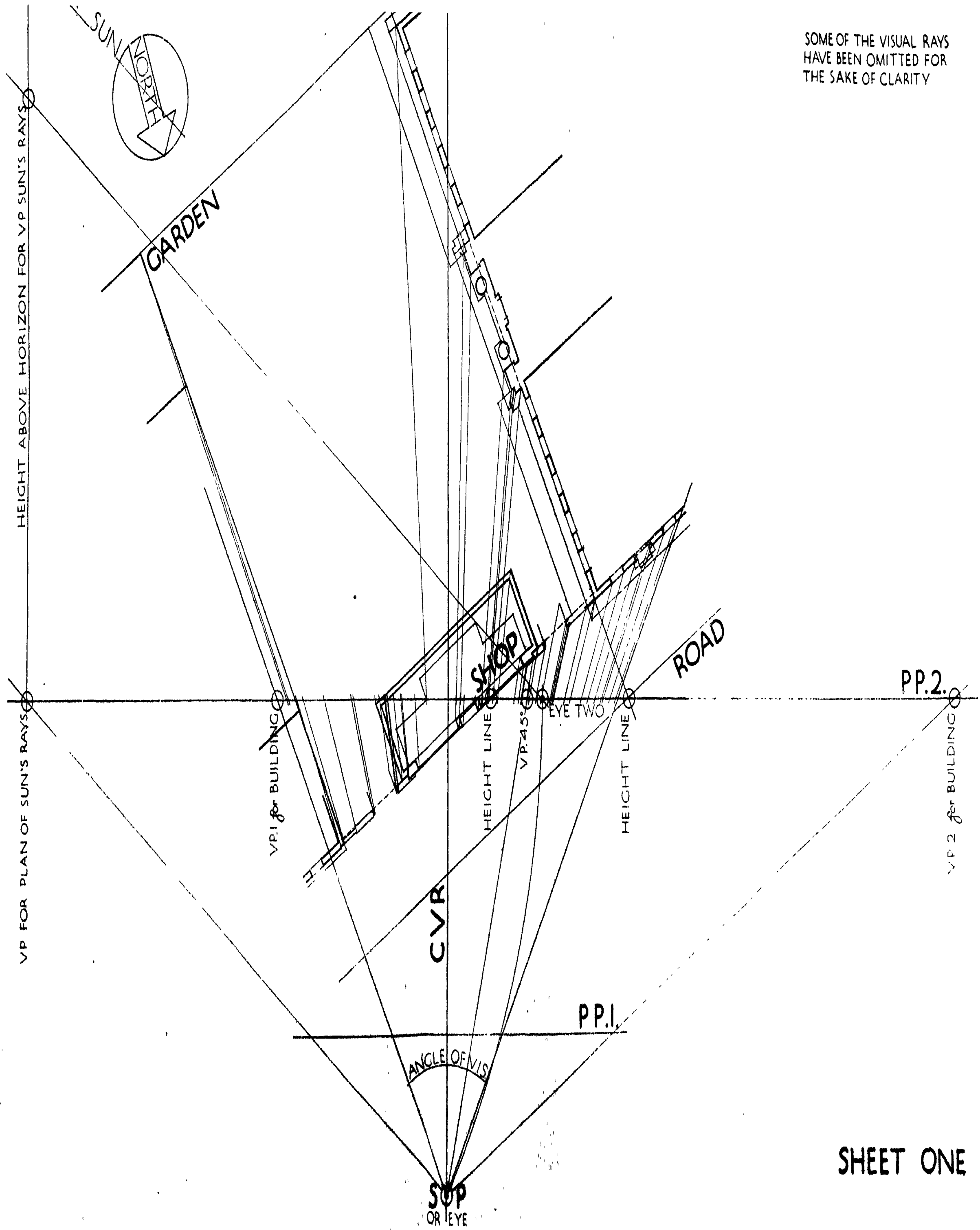
THE SAKE OF CLARITY



SHEET ONE

Chapter VIII—RENDERING

THE rendering of architectural drawings is considered by some to be a merely luxurious exercise, and one which is adopted in some cases to hide faults and weak drawing in both design and construction. Rendering, however, is distinctly valuable when applied to all drawings which have more than one plane or plan presented in their elevation which need to be explained. It is rightly considered to be a conventional treatment, and any attempt at realism should be suppressed, as it is calculated to produce distorted and unfortunate results.

Formal rendering may be said to possess two great advantages—the benefits of the general discipline of colour and tone which it demands from the draughtsman; and the lucid presentation of certain facts in the order which the designer intends to convey them. It is purely a study in tone values, and no introduction of colour should be allowed to upset this formality; its object is to explain at a glance the various planes, with their voids or openings and their projections or modelling, by means of washes of tone and shadow. It does not seek to disturb the pure elevation, and perspective, or a three dimensional quality, is not desired; only in the case of an assumed long distance standpoint should any perspective effects be introduced into the foreground.

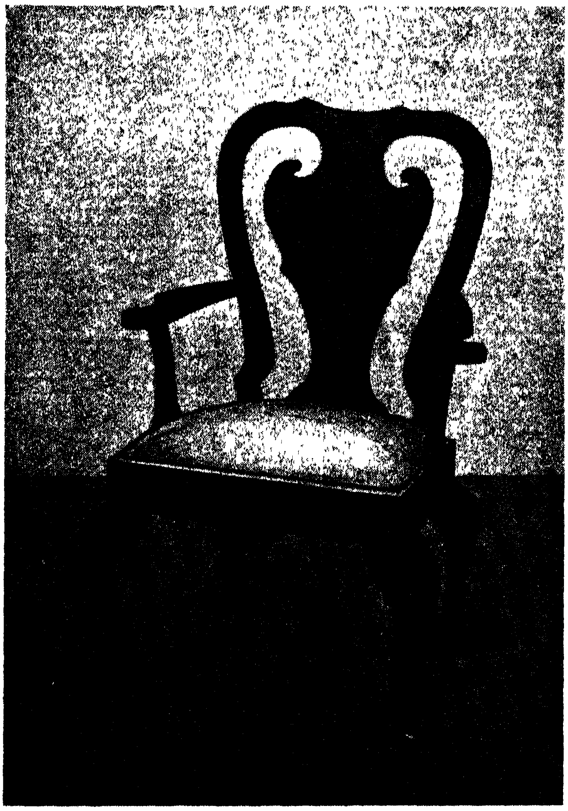


FIG 82. SIMPLE RENDERING. A WALNUT CHAIR

In any case, such foregrounds should be made entirely subordinate to the main elevation, and any "setting" employed should be consistent with it in treatment. A highly conventional treatment should not be supported by natural or realistic surroundings. The same thing applies to the rendering of plans, only that quantity being employed which is necessary to elucidate the functions and form without hiding the detail in any way. The "circulation" of the plan should be made perfectly legible, the main points of interest and the various major and minor parts of the composition being emphasized and indicated in such a clear and concise manner that the general form and character of the design may be understood and appreciated almost at a glance.

Most modern rendering has been developed from that which has been the custom of the Beaux Arts (Paris) studios (ateliers), but in the hands of our own men it has been somewhat simplified and chastened into a greater semblance to rational facts. The French *rendu*, while showing a set of qualities which were wholly admirable, yet, by its perfection and its adroitness, assumed too much rigidity and too many conventions. An architectural composition or design on a large scale is born out of a central idea, and contains various units in the plan which must be kept subordinate;

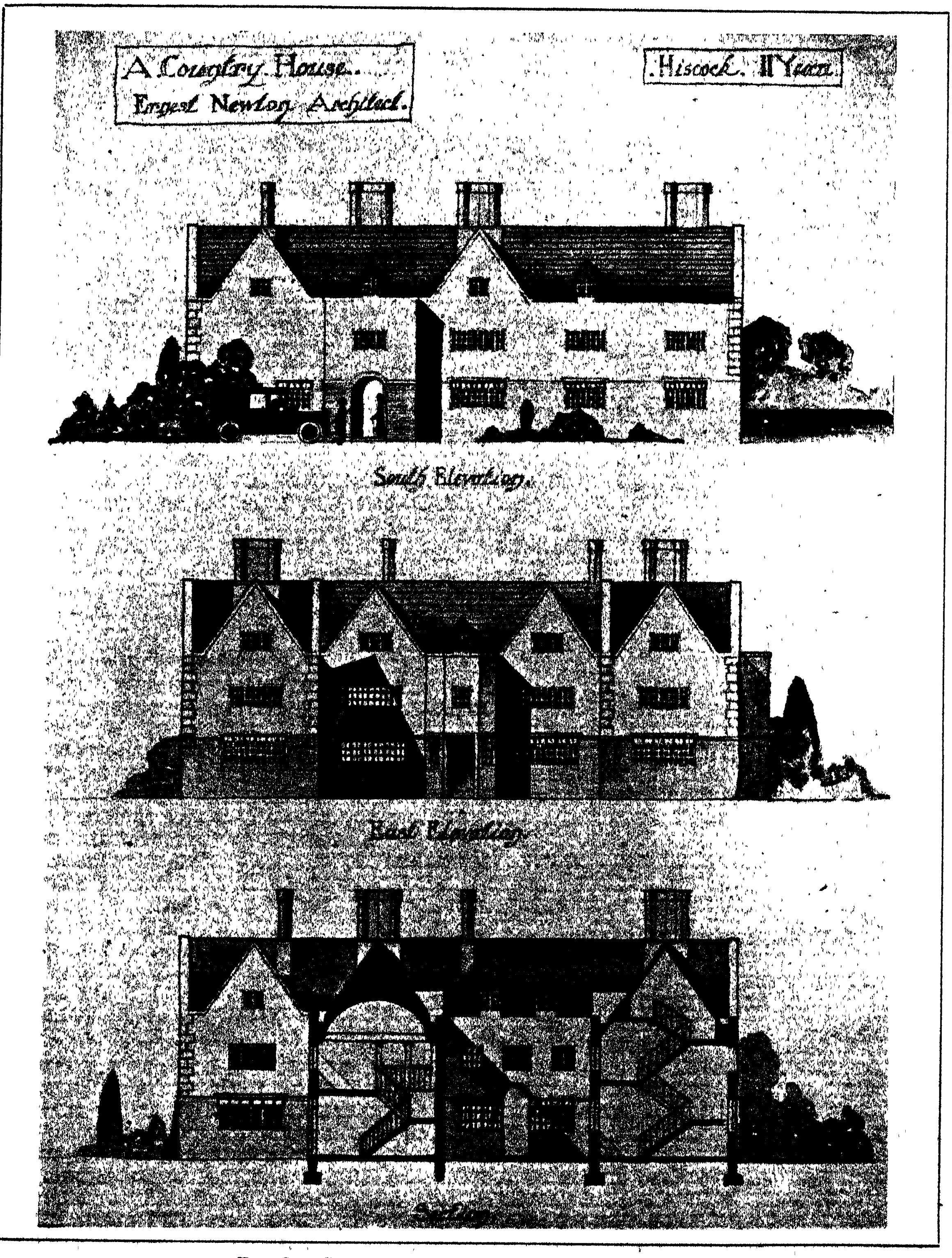


FIG. 83. SIMPLE RENDERING. A COUNTRY HOUSE

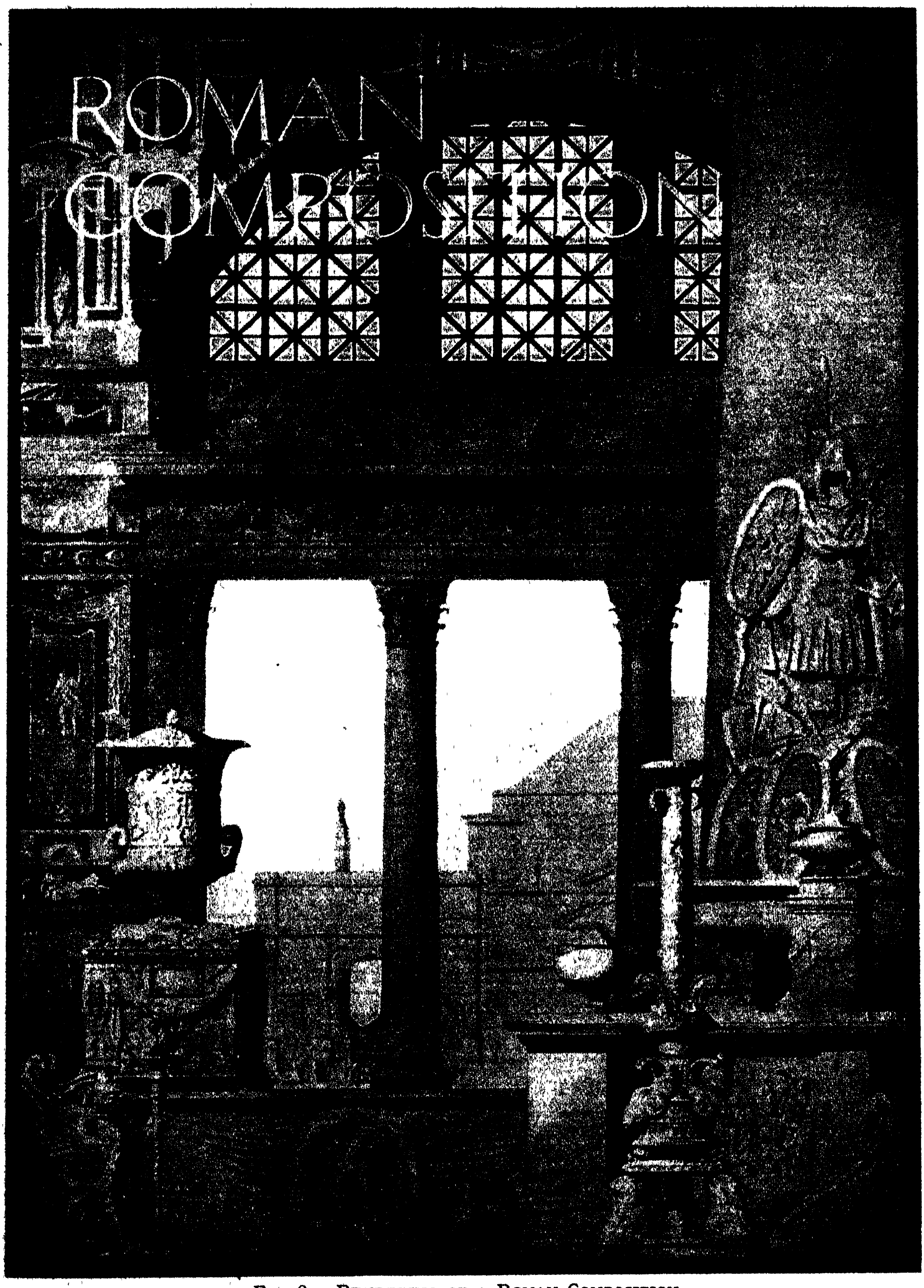


FIG. 84. RENDERING OF A ROMAN COMPOSITION

for example, passages, services, "usual offices," etc.; the elevation also contains similar subordinate material, as decoration generally and planes which, though actually visible, are yet secondary ones. These facts, then, must be sifted and placed in their relative positions of importance, so that the observer shall see at once what the designer is anxious to express.

The application of shadows is in some cases the simplest and most rapid method for such effects, but only the principal forms will be affected, unless the actual tone of one plane behind another receives a different treatment.

Fig. 82 (walnut chair) presents a very simple solution to a problem of the representation of textures, and will serve to remind the student of all those points of technique which were dealt with in Chapter IV on equipment and the properties of papers and colours. In the present chapter we are more concerned with "how to do it," and the rendering of the chair can be studied with advantage. The student will by this time have made some experiment with his washes, have explored the realms of "sediment" and textures, and will realize that this drawing of the chair is a bold essay in simple washes of strong colour. First, a grey sediment wash over the whole paper; secondly, when the first wash is dry, another wash of a dark warm colour over the chair and ground; thirdly, on top of the second wash, a green wash for the upholstery; and the completion of the shadow sides of the wood in darker yet simple tones. A few flicks of "texture" on the walnut back and the legs complete the scheme. High lights could have been picked out very easily from these colours had they been desired. This simple method should certainly be tried out before any more elaborate elevations are attempted, but the process is very similar in many circumstances, and courage is necessary to wash over a drawing which is already carefully made.

Fig. 83 (a country house) is a good example of the rapid effect of actuality which is gained by the use of cast shadows and the minimum amount of rendering. Here the textures are indicated by means of varied tones in the slate roof, brickwork, and ground floor, with but few accessories to wed it to a country setting rather than that which is consistent with a town. Actually there is no background wash in this drawing, but very little imagination is necessary to realize the value of a light wash to relieve the wall treatment. The windows have first been blacked in solid, and then the frames have been drawn in Chinese white. This is a little harsh and only suitable for such a domestic treatment; it is a good preparatory exercise, however, and contains several problems suitable for the enthusiast in shadows. A sheet containing three such distinct *motifs* might be very easily over-rendered. Note that the shadow from the porch in the south elevation is so solid and heavy that it competes with the car, bringing it up to a similar level and falsifying the quality of the material on which it falls.

Preliminaries to Rendering. We cannot do better than take as an example Fig. 84, a Roman composition by a student in the second year at the Architectural Association Schools. The object of these compositions is to teach massing and grouping, and to familiarize students with good classic detail. They are also valuable as essays in the technique of rendering and general expression, both in line and tone. Imagine, then, this study drawn in clean, hard line—all detail has been designed and settled, and a small tone study has been already prepared containing the main characteristics of the final scheme. The procedure is then somewhat as follows—

1. Sum up the sequence of the planes with their relative shadows, realizing from the imagined plan how far these planes will be affected in tone.
2. Cast all main shadows and fill in with a very light tint of colour to enable the rapid appreciation of their effect.
3. Strain the sheet down to the board, as already directed in Chapter I.
4. While waiting for the paper to strain out, clean and prepare all bowls, saucers, colours, brushes, etc., *and* get out a sponge and some blotting paper.
5. Decide upon the main scheme of rendering to be adopted, for example whether it is desired to make a grey or brown scheme, and whether "colour" should be introduced at all. This decision will be the outcome, mainly, of the dominating materials of the scheme, such as marble, brick, grass, or stone, and should always be strengthened by the preparation of a final small-scale sketch which will express the main points. not only of the tone of all textures, but the general tone of the composition.

A "safe" warm grey mixture may be tried first, such as yellow ochre and ivory black, with small additions of the warmer ochres, such

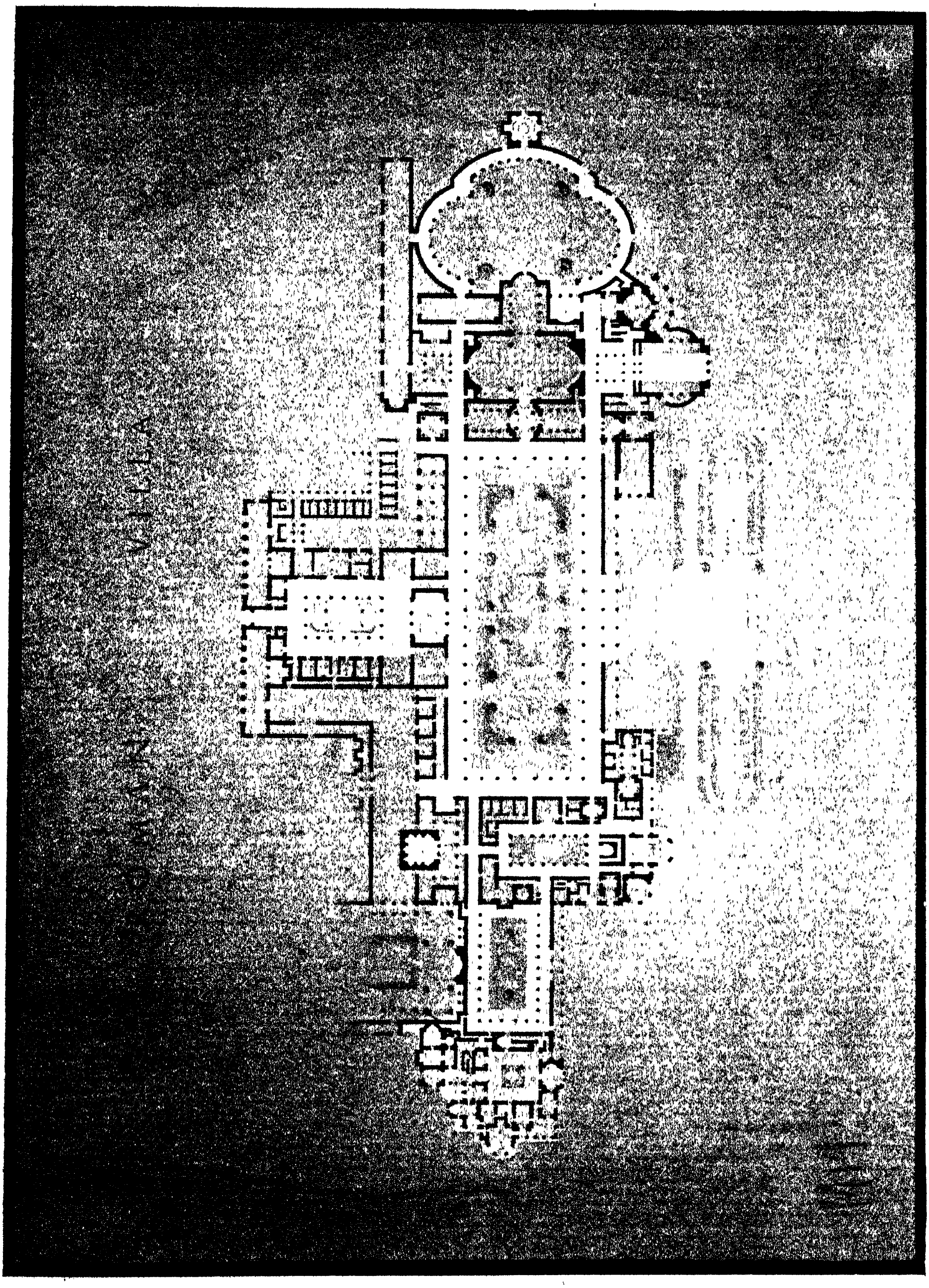


Fig. 85. A Rendered Plan

as raw sienna and burnt sienna or sepia. All these colours should mix easily and without causing much future trouble. It is wise, however, to try a wash or two of varying tones on similar paper and, having finally decided upon the several tones desired, to mix up a sufficient quantity of the colour for the requirements of the drawing. Keep a little very dark mixture in a separate saucer for immediate use (at any strength) in case it should be needed.

4. Build into all the shadows; sharpen up all the detail as necessary; add loose floating tones to those portions one does not want to insist upon; and, finally, key up all the work with crisp pen or brush detail in the silhouette of openings, edges, and ornament. The name "Roman Composition" is obviously added right at the end with process white. Incidentally, always work against a rough frame of brown paper strips pinned on the board, and

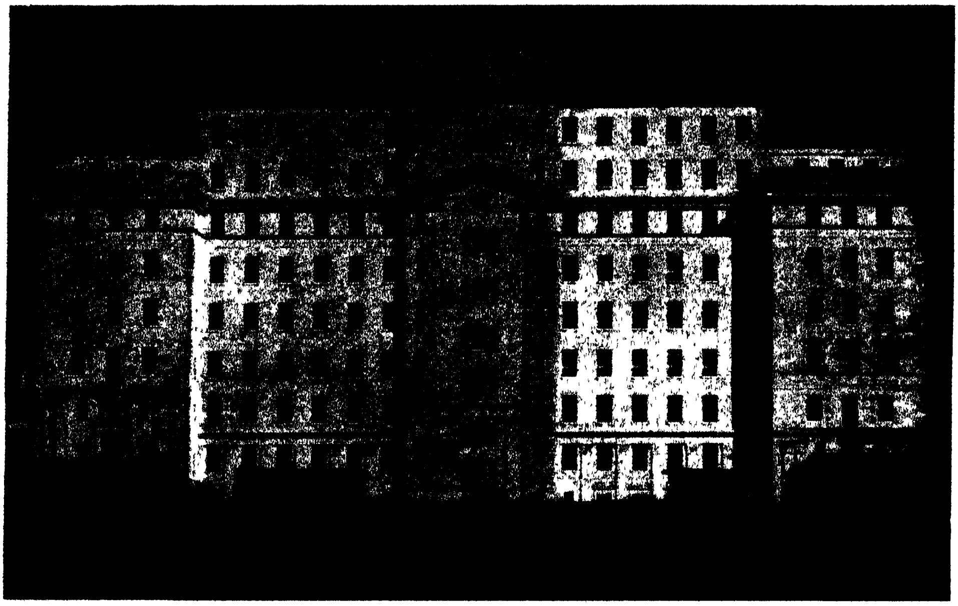


FIG. 86. BUSH HOUSE, KINGSWAY, LONDON
(With acknowledgments to "Architectural Review")

put the drawing at a distance or under a diminishing glass as frequently as possible, to be able to judge the effect of spots of light or dark. This drawing was rendered in about two days (16 to 18 hours), although the drawing and composition had taken the remainder of a fortnight. It is fine and elegant in its conception, bold in its execution, and most decidedly Roman in its atmosphere.

Applying Washes. Proceed as follows—

1. Put a wash all over the paper, grading the wash fairly suddenly towards the highest part of the scheme. Turn the board upside down for this and any similar operation, and *do not disturb the wash while it is wet.*

2. Lay on another wash over the whole of the sheet except the sky openings. This wash might be taken over the grille with little harm, because of the strong contrast afforded later on by the bronze work.

Follow on this system with all the various tones until your small sketch is reproduced on the final sheet.

3. Consider the "focus" of the corners, and if necessary run further washes (starting from water) into them to "lose" their insistence (see top right hand of Fig. 84).

Rendered Plan. Fig. 85 shows the rendered plan of a Roman villa, and is a fine example of careful drawing and rendering, and after our detailed description becomes easy to understand and appreciate. Here the problem is to elucidate an elaborate plan, and a moment's comparison with the same plan as drawn in pure line, such as an old engraved plate, will make obvious the advantages of judicious rendering.

Fig. 87. Rendering of Roman Doric Order

The main scheme reads easily, the " circulation " is distinct, the " offices " are made subordinate to the main courts, and the weight of colour has not in any way hidden the detail. Note the use of the " spray " in the upper portions of the scheme, and the not too conspicuous lettering of excellent type. This plan was rendered in Indian ink which had been ground from the stick and strained through muslin after settling; this is a very beautiful liquid to work with, but, being almost indelible, one which needs considerable care in handling. The majority of the finest early work has been done in this way.

Fig. 86, Bush House, London, is actually a photo, but is illustrated because of the similarity in treatment to a rendered elevation. Note the brilliancy resulting from changes in tone on various planes, and the way in which all shadows from small projections appear to belong to the plan which contains them. The dark sky is effective, and for a large treatment very useful, allowing much more simplicity in the general handling. Note how the top story recedes from the view, and also the " weathering " effect on the left of the central projection.

Fig. 87, of the Roman Doric Order, is included as a good sample of straightforward work which gains most of its effect by strong direct shadows. Here, again, a wash was taken over all the paper, with the exception of the section, and strengthened by successive washes in the background and the shadows. These shadows are not highly rendered, and it is a good plan in similar circumstances to proceed by flat washes up to this stage, and then with an old brush to scrub lightly into the reflected portions of the shadows, picking up carefully with blotting paper. For small scale work this is a much simpler method than trying to render the shadow strips from light to dark while the colour is wet.

The information offered in this chapter refers to the actual manipulation of the brush or point upon the paper in order to represent and describe a variety of surfaces; it might well be assumed to be the minimum amount of skill required by the student wishing to be able to show his work effectively to the onlooker, or to his client. With this in mind he is strongly recommended to work the exercises and to complete them in as many different media and methods as possible, for, as is well-known in other forms of skill, it is only through complete mastery of the technique that the apparently simple facility can be maintained.

The practice of producing elaborately rendered drawings, so dear to the hearts of the former Beaux Arts students, has ceased; they are no longer considered necessary even for the more important competitions and prizes. Indeed the pendulum has swung over to the opposite extreme and present-day drawings reflect a desire for extreme simplicity.

Only the essential things are shown, surroundings and "accessories" are avoided as far as possible and, frequently, drawings are finished in pen-line of varying "weights." In such drawings the surroundings, trees, etc., are suggested by a ragged outline, sometimes with the leafy interior left blank while at other times merely drawn over the elevation. On the plan such trees would be indicated by a simple circle.

All this is very clearly shown in the design for a Hikers' Hostel (Fig. 88) which is in pen line, freely drawn. Here the character of the local materials is suggested in the treatment of the stone walls and slate roofing; even the water is conventionalized. This drawing is obviously made for some easy form of reproduction, rather than for any form of subtlety in its rendering. As a point of interest, the stonework is indicated in the "plum pudding" convention, a fashion of the moment only, instead of being drawn in courses as it would almost certainly be built.

The second design alternative (Fig. 89) is executed in charcoal, rubbed into the paper, and conté crayon, lightened with the eraser where required. The lettering is obviously stencilled and the whole final effect is one of considerable strength. This method is selected because it can be achieved very rapidly and effectively in such a medium. Incidentally, the finished drawing (illustrated) was made on a detail paper drawn over the rough preliminary set-up, an extremely useful method in vogue for rapid presentations.

Contemporary architecture is naturally of utility character, and many former classical motifs of decoration are now absent from the architectural façade. The consequent simplicity in elevation inevitably affects all forms of presentation; the simple line drawing is therefore perhaps suitable and justified by the national austerity.

The simpler the form, however, the more difficult it is to express on paper and the "wide open spaces" of a modern flat façade become somewhat empty without an expressive technique. Shadows are, of course, the simplest

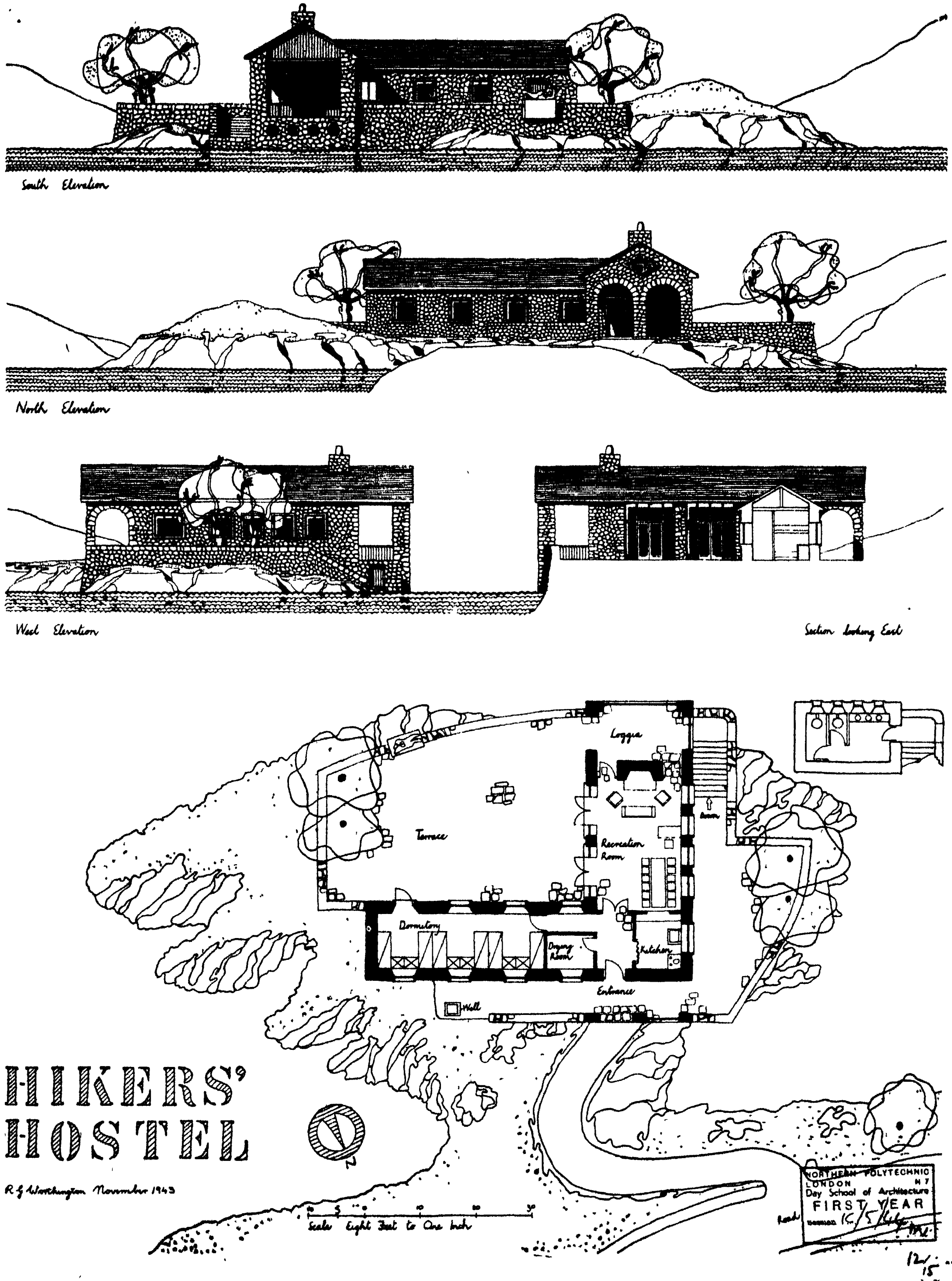


FIG. 88. A STUDENT'S DESIGN FOR A HIKERS' HOSTEL

method and the information given in Chapter V is therefore a most important subject for the draughtsman to study and master.

Shadows and perspective are very closely related, and the "sketch perspective" offers a ready and valuable aid to a three-dimensional and clearly visual expression of a scheme or its solution. For example, a "planning" scheme is much more readily indicated in perspective than in plan and elevation alone. "Vistas" can be easily shown and the co-ordination of one building with another, or with their surroundings, can be quickly emphasized. The architect can think easily around a perspective view while the layman finds it extremely helpful in visualizing what the architect wants him to see.

It may not be amiss then, to repeat the few headlines of this chapter in order to indicate the essentials for good successful work.

FIG. 89. ANOTHER DESIGN IN CHARCOAL AND CONTÉ CRAYON

Experience is essential for good quality work and every opportunity should be taken by the student to obtain it. After the few preliminary trials, large scale work is recommended, and observation in contemporary magazines of rendered work will afford much information to the draughtsman. You cannot render well with small brushes or bad ones, or with only a little colour, or with nervousness, and nothing should

be allowed to hinder a bold wash on a large surface. To render large drawings mix plenty of colour, slope the board with paper strained tightly, and take a large mop brush full of the stirred colour to dripping point. Starting at the left top corner, work the brush quickly but firmly across the paper, allowing the colour to *almost* run down. Continue with second and successive lines, but always joining with a wobbly line and collecting the previous colour as you proceed. The first brushful should be still wet and shining when the last stroke is made. *Do not touch* the work again until dry. If the paper cockles it is not strained sufficiently, and should be a warning for the next occasion. A light sponging immediately before starting a wash assists the graduation of the colour, but it is perhaps better to sponge or brush lightly after the wash is bone dry. Edges can be trimmed up afterwards and need not be considered ; some of the best washes have been laid after a succession of failures and spongings. Many of the best drawings are washed and sponged several times, and therefore need good, clean, hard drawings in preparation. Keep changing the water pot, do not disturb or repair a floating wash, drain all surplus colour to the corners, and leave all corrections until the colour has dried. Remember also that a dark rendering needs a strong line drawing, and that a wash that looks hopelessly dark when wet usually dries much lighter.

Lettering. Another important effect of the mechanistic character of contemporary design is reflected in modern architectural lettering, both in the use of the actual letter on the façade and also in the "titling" and information on drawings. On drawings the design of the letter has also become mechanical, produced and formed with the help of stencil plate or fountain-pen, widely spaced and frequently made with the wide letter equal in width to the narrow one.

This is in strong contrast to the incised classic form already quoted and discussed in Chapter IV as the best basis of study. However, legibility must never be sacrificed to variety, for, if lettering cannot be read it obviously fails in its job.

On the façade (and internally as well), the modern letter is no longer restricted to the panel but has become an extremely important part of the general design. Letters are constructed in a great variety of material, some made several inches deep in order to catch the light or the shadow. The Neon light is a well-known and obvious use of line-lettering, conforming only to the glass material; wood and metal, painted and illuminated, are also frequently used.

It cannot be urged too strongly that such simplicity of treatment is the product of a highly trained draughtsman; that "what to leave out" is just as important as "what to put in." Mere imitation, while perhaps flattering, is a poor craft for an ambitious student.

It is only through earnest study and personal practice that real progress can be made; no apologies are therefore necessary for information given as a variety of exercises, small in themselves but essential to the final desire to become a really efficient draughtsman and designer.

Chapter IX—ARCHITECTURAL SKETCHING AND MEASURED DRAWINGS

HOLIDAY sketching and Museum Work have already received some slight notice under the heading of "Museum Study" in Chapter III, in which the practical methods of study were given in detail. The importance of continual practice and progressive exercises, however, cannot be overstated, and, assuming that such experience has been obtained, we must now consider the more general aesthetic branches of our work. In former days, the architect was not considered to have completed his education unless he had in some measure made the "grand tour" of France and Italy to sketch and study as many buildings of architectural merit as was possible. This must have been extremely laborious and expensive, and in these modern days we are saved much travelling by the proximity and general excellence of our many museums, which in the majority of cases classify their contents so ably in books, photos, and actual examples, that a student having but the barest outline as guide can readily compare and analyse his subject. This comparison is most necessary, and any work undertaken should find its niche among the student's notes of historical sequence, whether it is considered as planning or the treatment of elevation with its decorative detail; indeed, some system of comparative study should be the first thought in the planning of a holiday sketching or measuring tour.

Much loss of opportunity will be saved by a little previous study of guide books or textbooks which outline the chief objects of architectural interest in the districts which will be visited, and photos or post cards should be obtained, whenever possible, to accompany the work done; indeed, they are of great value for interior decorative details, etc., if notes of colour and material as well as historical data are made on the back. Museums cannot always supply the same spirit and colour of the work which is seen in situ; such details as cornices, for instance, should always be considered in relation to their actual height from the ground, and many other objects come within this requirement. A sense of "scale" is very difficult to acquire, whether it is applied to a façade of a single building in relation to its neighbour, or to the numerous details of the elevation in relation to each other and to the whole scheme. It is much easier to comprehend scale from actual buildings than from objects in museums, which are invariably isolated from their natural surroundings, and for this reason alone every opportunity should be taken to study and analyse such details in the position for which they were designed.

Architectural sketching may, therefore, be defined as the analytical study of architectural design, noted in such a way as will supply to the memory the main facts of size, scale, colour, or material; whereas *measured drawings* should be precise statements of these facts drawn to scale in the medium which will best express them, and with the utmost sympathy and research. The latter method necessitates the closest observation and knowledge of the contemporary methods of construction, while to be able to express such points presupposes a considerable experience with the sketch book and with general methods of draughtsmanship. The two branches are, therefore, very closely interlocked, and the more the hand and eye are trained to express these points of interest with certainty, the greater is the freedom given to the brain to compete with the more analytical side of such research.

There is no doubt that a sketch book containing notes of the date of historical forms, with comparative treatments and sizes for particular purposes, is of far more value than a limited number of drawings carefully and minutely executed as "medal snatchers," particularly when the student is touring among districts of distinctive character of material or design.

Order of Subjects in Museum Work. The museum is essentially for study, and some method of attack should be mapped out in order that a sequence of thought may be maintained. The student will gain invaluable knowledge and freedom of execution in actually measuring and drawing his programme; he might, therefore, in his wisdom choose to group his subjects. These groups might be as follows: materials

(Architectural Association Sketch Book)

FIG 90. SKETCH MEASURED DRAWING, VILLA BORGHESE, ROME

—wood, stone, brick, marble, and plaster—and the study within these departments might include façades generally, viz., treatment of features, doors, windows, and openings. This will lead him to details such as sculpture, iron and bronze work, terra-cotta and glazed majolica (e.g. della Robbia), and finally to the interior with its details of panelling in both wood and plaster, its decorative treatment in carving or colour, and its contents of furniture and equipment. This is but a general outline of a programme, and could obviously be applied to many other branches of architectural work. Care must always be taken to note all the various methods of construction as exhibited by the jointing, etc., and to show such facts upon the drawing. If a similar scale is adopted wherever practicable, a great many points of comparison will be easily recognized, while half-imperial sheets form a valuable basis for a folio of practical reference in the later stages of his studentship. Photos can be filed in this folio with any reproductions of similar types of work which can be obtained, and classification from time to time strengthens the memory of the objects studied.

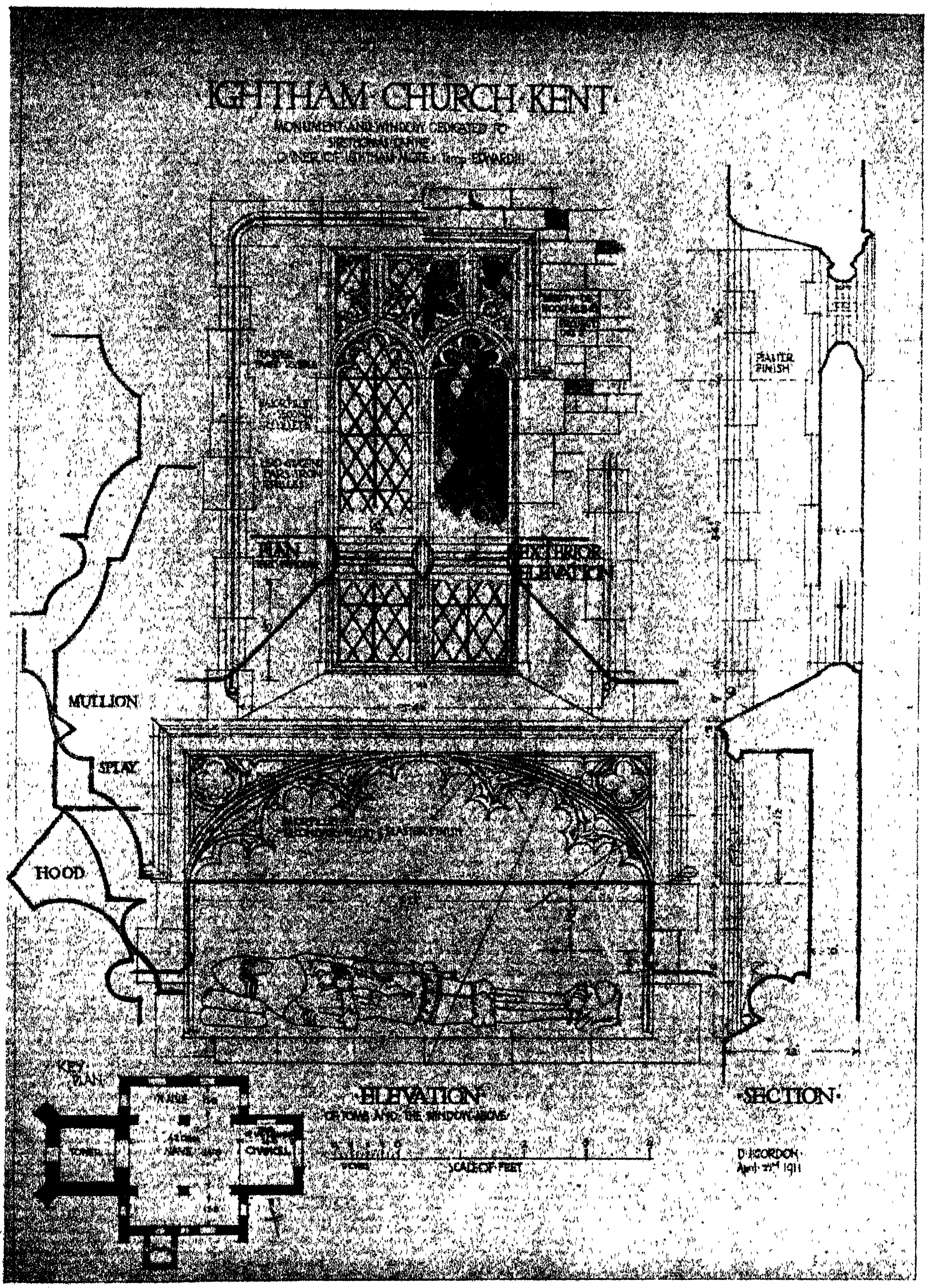
Measured Drawings

When the student has gathered confidence from the work he has done in the museum, he should begin measured work on the actual buildings around him, if possible, beginning with small things of definite utility; for example, doors, gates, towers, stables, small bridges, village crosses or tombs, etc. This will lead to larger schemes: houses (of all materials), small churches, market halls, schools, even up to town halls. Comparative types will then be obvious, for example English, French, Italian; Norman, Gothic, modern; brick, stone, or steel, with the decorative side of each particular period fully explored in the details of carving, mouldings, glass and its heraldry, marble, the employment of colour, etc. It will be readily understood that such a scheme involves a great quantity of work, which can only be fully accomplished by the man who is trained in all branches of drawing; but the early studies in the museum of small and readily understood objects can now be extended, and the comparative comfort in which they were made be compensated for by the acute discomfort of the dizzy height of a tower or cornice with wind and weather in an unfriendly mood.

Sketch. The reproduced drawing, Fig. 90, by the late Alick Horsnell, of the Garden Gateway, Villa Borghese, Rome, is an admirable example of sketch measuring; his work was always keen and surely drawn with swift precision and knowledge of the material and detail, and containing a very fine sense of pictorial composition and artistic freedom. This example is primarily a sketch giving a very adequate impression of the situation, but is supported by detailed mouldings, plan, and dimensions, which would enable him to reconstruct the gateway at any time. Note the treatment of the wash shadows, the indication of materials, and the arrangement on the sheet as a decorative but, incidentally, very artistic drawing.

Stonework. The monument and window in Ightham Church, Kent, shown in Fig. 91, is another excellent type of drawing, and similar subjects for study may be found in nearly every church in our towns, and sometimes villages. The subject is small and complete, giving good experience in both free-line drawing and geometrical work, with most interesting treatments of material. These old "memorials" were usually demanded from only the best local workmen, and can usually be trusted to illustrate the best work of the particular period. The craftsmanship is usually very fine, and traces of the use of colour may very often be found either on the stone or in the glass, with its contemporary heraldry and armoury lending distinct interest to the work. This drawing is clean, precise, and workmanlike; the details of the exterior and interior are given both in elevation and section, and the small plan which indicates the position of the monument is excellent practice and worthy of note. Look at the accuracy of the geometrical work, the methods adopted for dimensions, the sections illustrated at all the necessary points, the treatment of the various materials, the use of a good type of lettering, and the general design of the sheet, not omitting the provision of the scale. A very good drawing of a simple stonework subject.

Italian Renaissance Work. Figs. 92 and 93 are drawings of the Church of Santo Spirito, Florence. These two illustrations are part of a large set of measured drawings by the author, representing an elaborate subject with ample scope for measuring and the careful plotting of the details. This church is one of the best samples of the work of the Florentine architect, Brunelleschi, and was begun in 1436, though not completed until 1482; internally it is one of the



(Architectural Association Sketch Book)

FIG. 91. MEASURED DRAWING: STONEWORK

most nobly planned buildings in Florence, and is a good example of a church on the basilica plan, having aisles formed round the transepts and choir, with a flat wooden ceiling to the nave. It is probably the earliest instance where isolated fragments of the entablature are placed on each column with the arches springing from them. The sacristy was built by Guiliano da San Gallo in 1489, and the connecting vestibule by Andrea Sansovino is of considerable interest and beauty. It is reproduced as a good sample of straightforward measured drawing, carefully inked in and rendered slightly to emphasize the main portions of the composition. This illustration shows the most explanatory section of the building and includes the beautifully proportioned connecting loggia, and it will be noted that sufficient indication is given of the details of the interior to illustrate the furnishings, fittings, and general scale of the design.

INTERIOR. The procedure is much the same as has been already explained in connection with the museum study of a doorway (Chapter III), but is again considered in order to emphasize the methods of work. As the plan is of the straightforward cruciform type with regular transepts and aisles, this drawing does not present a great deal of difficulty in its solution and will serve admirably for our purpose.

After general consideration of the building, it is best to begin at the heart of the plan, which is that of a cross—like an English church —supporting the dome by its four piers and their pendentive arches. Plot these first of all, and measure the total width and length of the nave from the centre of the columniations (or bases to be more accurate), add the aisles and transepts, the thickness of the walls and other formations, checking the details as you proceed, and plotting them actually on the spot. Be careful to insert all dimensions, as they are plotted, on to the main "through" dimension line, with the details of arcading, etc., on the subsidiary dimension line, checking one with the other as you proceed. The plotting should be done to the largest convenient scale, but so placed upon the sheet that all the main elements of the plan may be included, and all later plans to a more detailed scale should be referred to this "master" plan by clear indications.

As soon as the main portions are completed, set up the sections from it, as may be seen in the illustration of the nave with its aisles, and check by measurement again when adding the main dimensions. For the heights, first measure from floor to top of the entablature, which will give the springing of the arches, drop a tape or weighted string from the main projections of the gallery, or other accessible spot, and measure upwards as far as possible by rods or windows, etc. Ceilings frequently have ventilation holes through which a string can be dropped to the floor for the main height.

EXTERIOR. Assuming you are now up to main internal height and inside the roof, take a note of the roof timbers—construction, size, etc., and particularly the pitch or angle of the timbers at the wallplate, which will usually assist considerably in plotting the roof. Many other details may be checked from external measurement; for example, the window sill to the eaves may be measured from above instead of below. It is very rare to find a building that is not accessible except in the case of the dome or steeple; for these, dizzy heights must be scaled occasionally, and plottings taken internally and externally to gain particular facts. Always plot as much as possible, even in a guessed or sketched form by proportion, before climbing to measure heights, so that as little drawing as possible may be required when endeavouring to retain your equilibrium on a somewhat insecure cornice. While you are up there, however, be sure to get details of all mouldings and enrichments—full size, if possible —to save any further peril at a later date. Thin lead strips, about 2 ft. long by ½ in. wide, are very useful for this purpose, and can easily be carried around the neck or arm until wanted, when they bend readily round mouldings and are traced around on the paper, care being taken to bend the lead in such a way that it will leave the moulding freely without distortion, allowing any hollows to be added later. Always note the sizes of tiles or roof covering for practical knowledge, and their overlap and repetition for the sake of the drawing; also, while on the detail, *always* measure two or three repeats of the mouldings or carving, and make sure that it is an average piece, and show how it occurs in relation to detail above it or below. The original sheet of full-sized details (Fig. 93) amplifies the small ⅛-scale drawings and shows different sections in different colours, to enable them to be distinguished with more ease; sufficient repeats are also given of the carving on the various mouldings. Note the way in which these F.S. (full size) mouldings are collected together on to a double-elephant sheet with comparative ease, though actually this arrangement needs a good deal of manipulation.

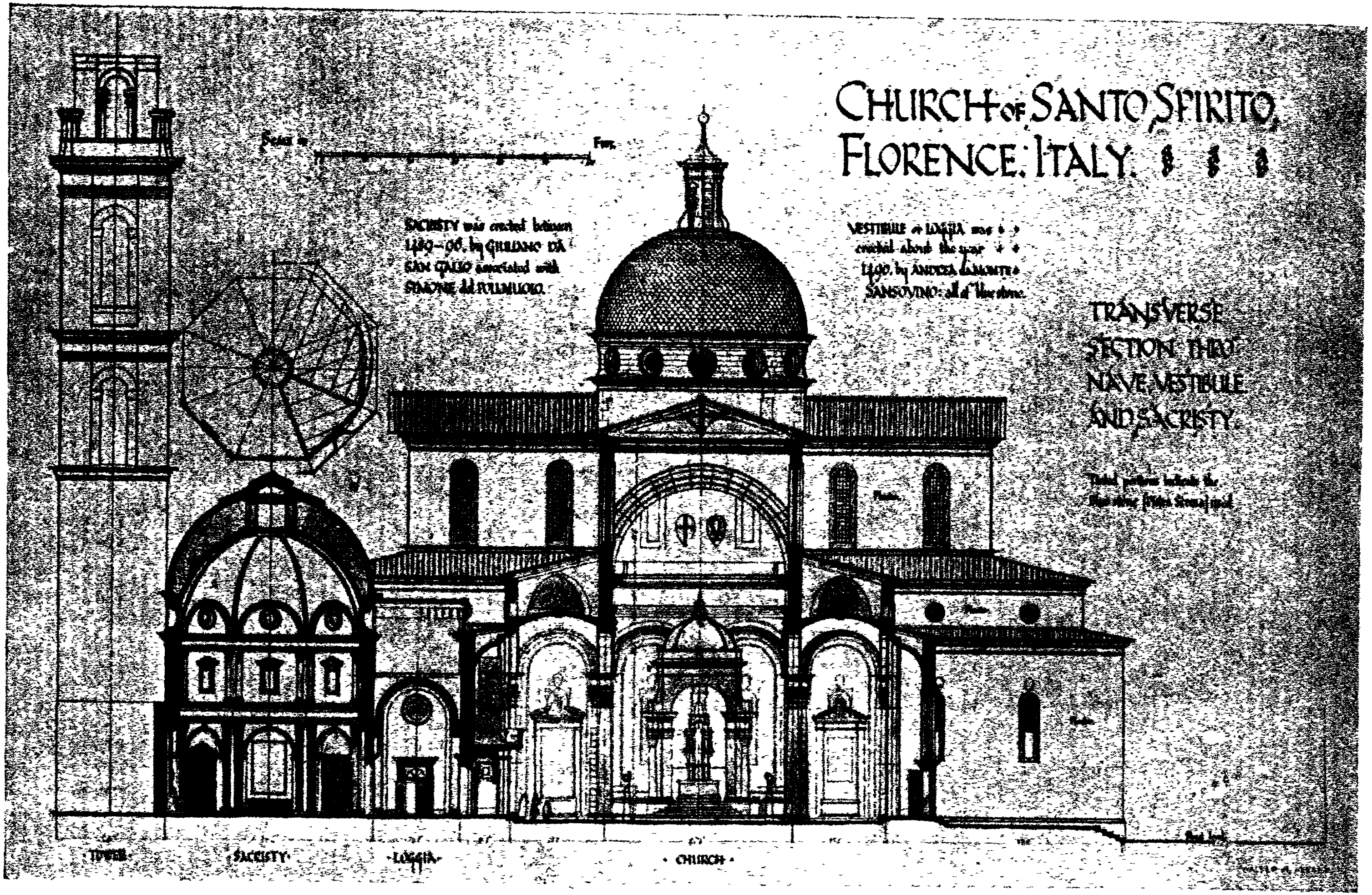
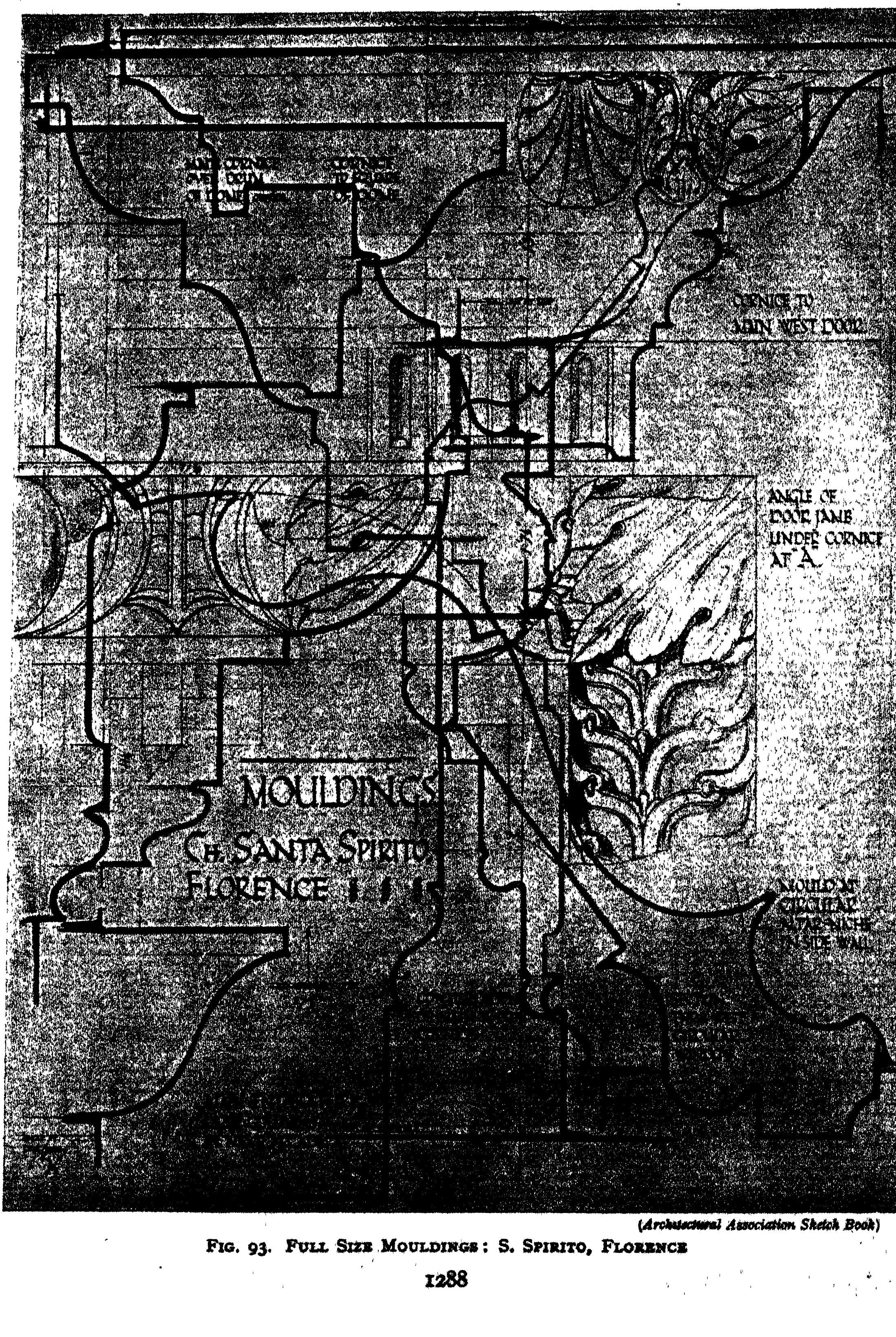


FIG. 92. MEASURED DRAWING: S. SPIRITO, FLORENCE

(Architectural Association Sketch Book)



(*Architectural Association Sketch Book*)

FIG. 93. FULL SIZE MOULDINGS: S. SPIRITO, FLORENCE

Of course, long, straight portions of the mouldings may be curtailed when necessary, as long as the dimensions are included ; the sheet is for expert information only, and as it is entirely related to the more general drawings, good, clear methods of reference should be applied.

Note, also, that all the lettering is in script, as being a little less formal than pure Roman capitals, and is kept in collected panels; this also applies to the transverse section, where similar lettering is employed and so designed as to complete the balance of the tower and the sacristy.

Brickwork. The Meat Market, Haarlem, Holland, illustrated in Fig. 94, was designed by Lievin de Key in 1601; it is a splendid example of stone and brick combination and is now used as a library. This drawing was chosen as representing very carefully measured and drawn work of a fairly complicated subject. The plan is, as can be seen, very erratic, and this means much trouble in the plotting of the various sections and elevations which are necessary. The detail is of an elaborate character, and the materials very varied, but the scheme has been indicated with remarkable fidelity, and the sectional drawings which were made, but which are not reproduced, are evidently the work of a man who was keenly alive to the decorative qualities contained in the structure.

Note the splay sections and elevations, the omission of all unnecessary repetition of complicated ornament, the indication of the materials and textures, the dimensions and the panel of lettering. The complete set of drawings is made with a beautifully clean line, very expressively drawn, and one feels that the measurements can be relied upon for their accuracy.

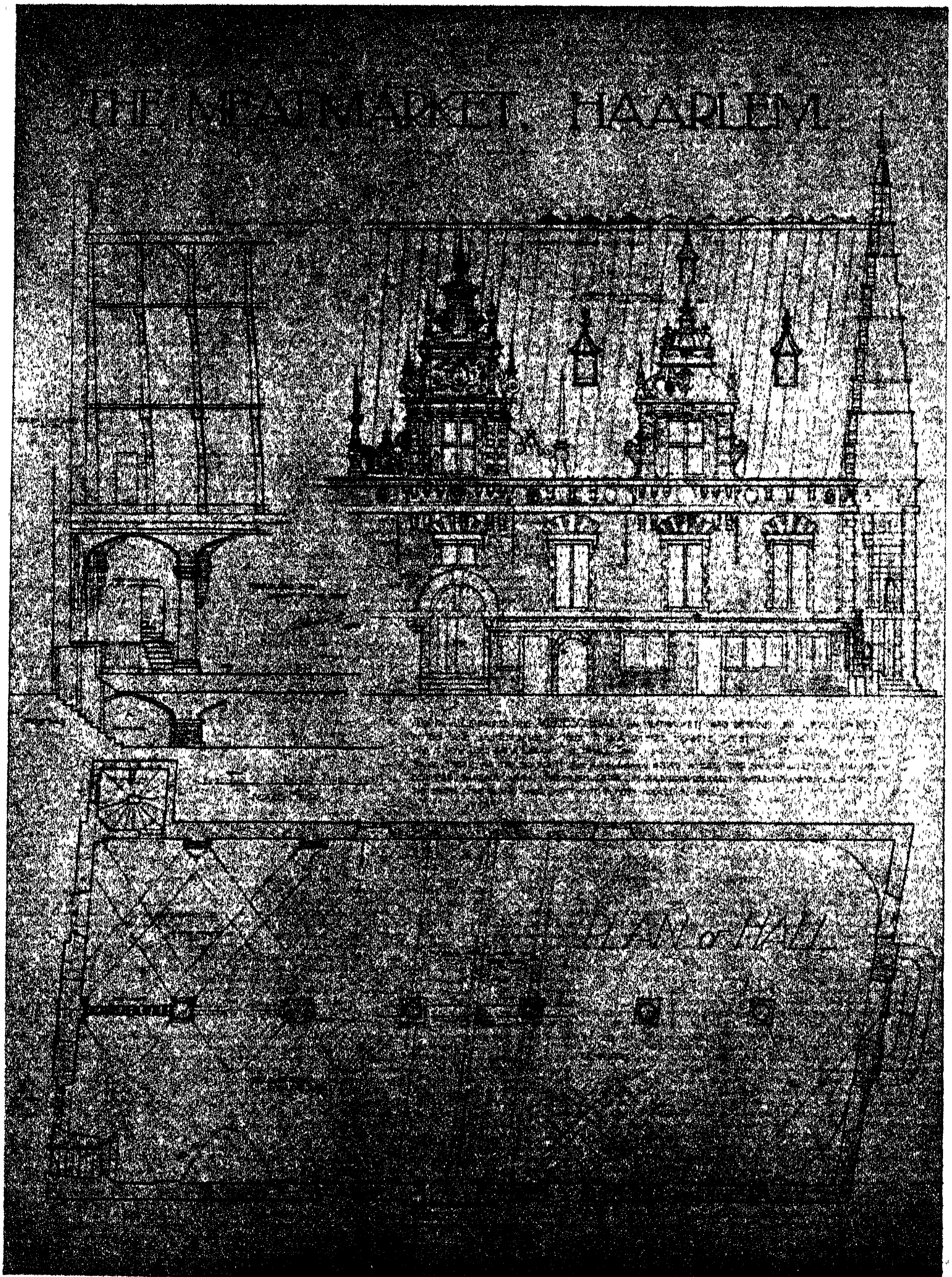
Whenever possible, the student would be well advised to study the various types of draughtsmanship which have been in vogue at certain periods in the past. The eighteenth-century work may appear rather simple and somewhat spiritless at a first glance and in comparison with present-day manners, but the smallness of the scale at which these drawings were made, the care and delicacy of line used, and the general attention to the main effect of the masses and openings—the " solids and voids "—with the subordination of detail, generally makes the whole scheme very consistent and legible. In many cases, with a Gothic type of building and its attendant tracery and geometrical work, this was no mean labour, and was effected mainly by careful grinding and straining of the stick ink, diluted with due regard to the delicacy of the treatment. For instance, the drawing made by Sir Charles Barry for the " Houses of Parliament " was about 4 ft. long, showed the complete façade to the river and all the distant towers in their true relationship, all in pure line, the more distant portions being indicated in a lighter tone ink.

The " Law Courts," Fleet Street, by G. E. Street, was another similar Gothic drawing of a later date, equally laborious in its careful detail. The drawings produced for the new Liverpool Cathedral by Sir Gilbert Scott are renowned for their delicate and accurate expression of jointing and carving, and numerous other modern masters have invariably produced beautifully drawn sets.

Further reference should be made in the various libraries to the reproductions of both old and contemporary drawings in the majority of the building journals, and to such standard works as the *Architectural Association Sketch Book* (with over thirty annual volumes), the *Liverpool Architectural Sketch Book*, and others. Local museums and churches usually contain some drawings which are of historical interest, and these invariably give interesting information to the architectural draughtsman.

Mediums and Effects. There are many occasions on which the architectural student is thrown among good examples of local work which he should desire to retain in his sketch book. The holidays are a fruitful source of study, and week-end jaunts to towns or villages of interest are also possible. The lighter side of study is thus combined with exercise in expressive drawing, and a few hints on the methods to be cultivated are given. The illustrations in this chapter are concerned with pencil, pen wash, and pen line, and are chosen to represent the merits of these simple forms of technique; the final results, however, must depend upon the degree of training received, and the most definite and vigorous forms of subject should always be chosen until experience has opened up other subject-matter.

The qualities of artistic composition should be considered in every sketch, for the desire to reproduce the object seen is naturally combined with that of expressing it in the most attractive form, which is "composition." A sketch is a trial study, and is considered with a view to a final choice of arrangement upon paper of the items of interest concerned. This choice can be made from the material on the spot or, as an exercise, from photographs or



(*Architectural Association Sketch Book*)

Fig. 94. Measured Drawing: Brickwork

other illustrations at home; but, in any case, the factor of choice is one which should be cultivated. Later stages will be concerned not only with this "design" of the light and dark portions of the picture, but with the expression of their materials also, whether they are of brick, stone, slate, foliage, sky, wood, etc.; and it will be found that the pen gives a quality which cannot be obtained with the pencil, and *vice versa*. On the other hand, given a definite medium, such as a pen line, an interesting exercise is to endeavour to express such elements as light, heat, and even sound! A blow on the head is frequently expressed in the comic papers by a series of radiating lines around the afflicted portion, and other similarly affecting results can readily be called to mind! Heat is most admirably expressed in the sketch by Mr. W. G. Newton of Seo d'Urguel, which is discussed later.

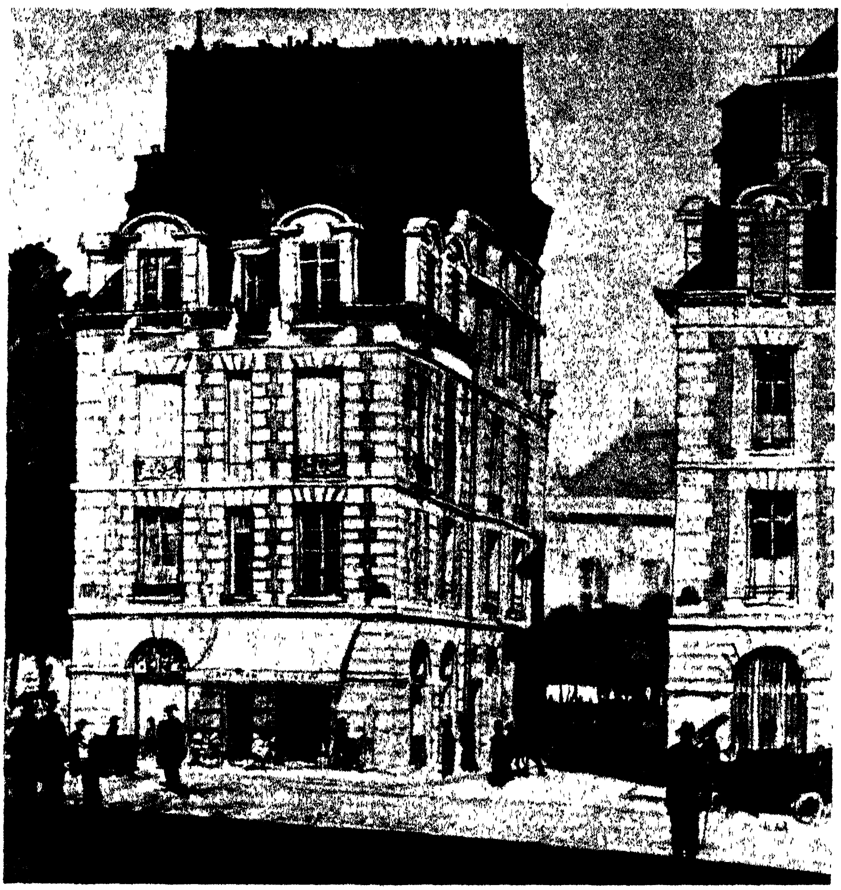
When the painter studies a scene, he makes a mental picture of the final effect as it will appear upon his canvas, and he generally precedes his work by making a few small sketches of his composition. These "thumbnail" sketches can be made in the roughest way, so long as they are intelligible to him, and the main principles of his pattern or design are put down rapidly together with the main tone values. Such small designs are most useful and help him to analyse even a large and complicated scheme; they give a "first impression" which can be retained to remind him of his first vision when his mind has, later on, become filled with the details of the scheme. Make a few rapid notes of any of these illustrations, and it will be noticed that the frame or border can be shifted to either side, or up and down to give a new composition of the objects. Having decided upon the position of the units, some thought should next be given to the qualities desired, the centre of interest, or the path of interest, i.e. those items which will assist to create the right scale and atmosphere. It is a good plan, when using pencil, to keep about three grades of lead or tone, e.g. HB, 2B, and 4B, so that equal pressure can be put upon the lead while yet obtaining varying qualities of tone suitable for different materials.

(W. M Keesey)

FIG. 95. PENCIL INTERIOR. TONBRIDGE, "ROSE AND CROWN"

Pencil Interior. Fig. 95, a pencil interior by the author, is a good sample of the use of strong blacks and definite whites, which assist each other to produce an effect of brilliant external

light. The whites are left almost clean for the purposes of pencil reproduction, still a matter of considerable difficulty, and an effort has been made to collect the tones together in order to force this comparison. Notice the strength of the table, which builds into and yet increases the effect of the window openings. Notice, also, how the path of interest has been chosen to exclude the details of the carpet, which, if included, would undoubtedly have worried the eye and detracted from the main interest.

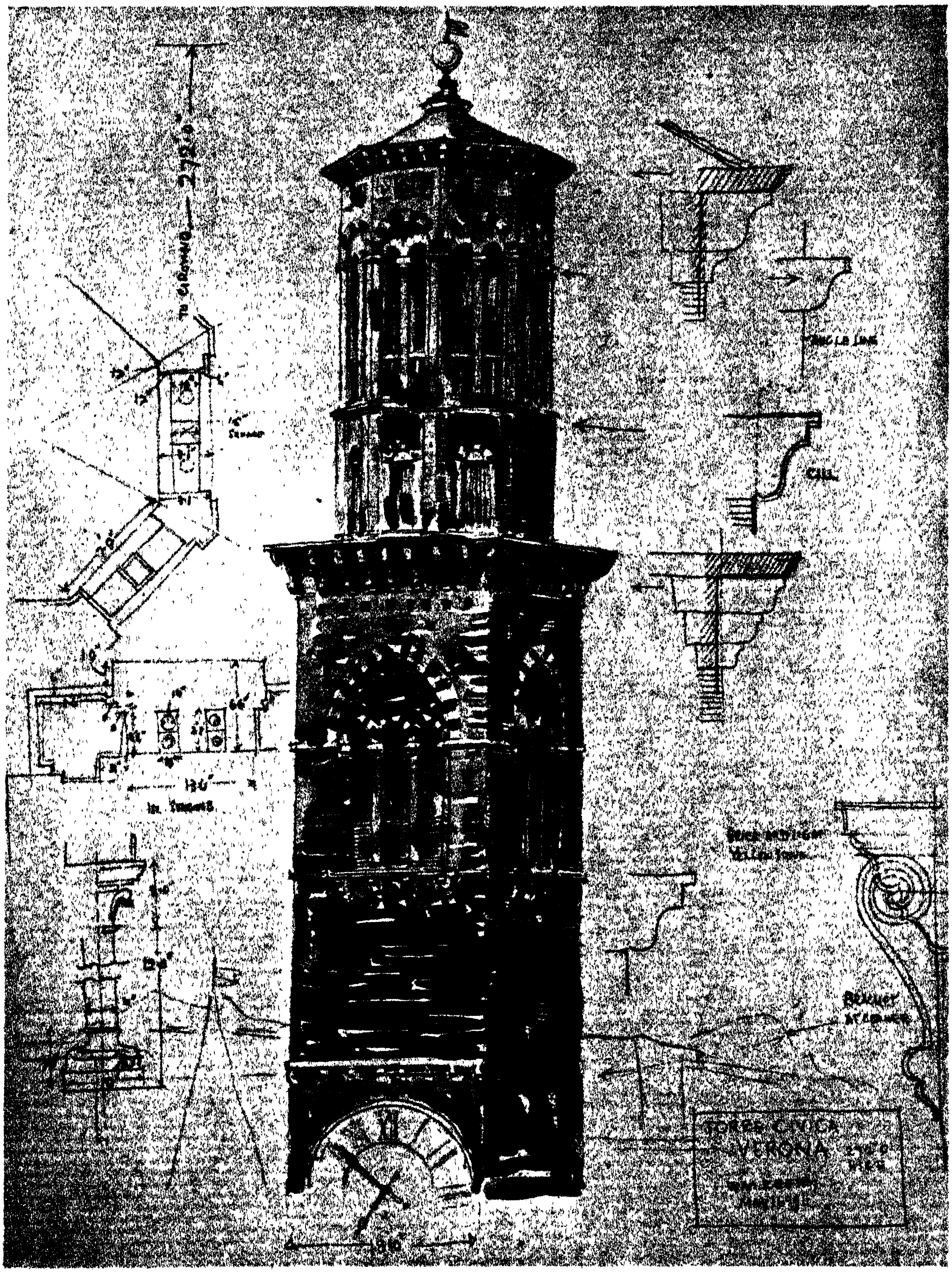


(*Keith Murray, A.R.I.B A.*)

FIG. 96. PEN WASH SKETCH

Sketch in Pen Wash. Fig. 96, a sketch in pen wash by Mr. Keith Murray, is another excellent example of the medium. The pen line is most suitable for delineating the detail of architectural features, but needs to be backed up by strong darks, such as the roofs and shadows; very considerable strength of mind is necessary in order to translate these roofs to strong blacks. The pen should become an essential part of the student's outfit, and a little practice will give sufficient assurance to show to him its permanent qualities. A good fountain-pen is a very good friend, and some inks are sold which allow considerable freedom from thickening, while still permitting a wet brush to collect sufficient colour from the lines to indicate wall details and tone values; a very good bottle ink is that known as "Prout's Brown."

Pen Line Sketch. Fig. 98, a pen line sketch by Mr. W. G. Newton, is chosen for its most expressive manner of manipulation. The majority of pen line drawings show a line which is hard and inflexible, giving equal strength to detail in light and detail in shade; in this sketch, however, the pen is used as the painter would use the brush with colour tones. The peculiar



(W. M. Keesey)

FIG. 97. TOWER AT VERONA

nature of the sun-baked walls and their overhanging eaves is fully demonstrated, while the whole composition is based upon the receding

(*W. G. Newton, F.R.I.B.A.*)

FIG. 98. PEN LINE SKETCH

though similar shapes of the walls that are visible. Almost theatrical, the street breathes heat and strong sunshine; and the surfaces, though almost devoid of incidental details, are yet broken up by the treatment of the pen. The lines in the sky and in the road suffer rather from reproduction, and are not actually so definite in the larger original drawing.

Sketch of Tower at Verona. Fig. 97, the ancient tower at Verona, is a further example of detail for the sketch book. The sketch was made from a convenient vantage point, while the details were added against their related portions after a visit and an inspection of the tower itself; these details are almost sufficient for a reconstruction of the tower and, therefore, serve their purpose admirably. This small sketch did not allow pictorial effects, but slight tinting of the material in colour produced a very adequate memory reconstruction.

Working Hints. Some consideration should be given, when forming a scheme of work, to the various "five-finger exercises" of drawing, which are as essential to the draughtsman as to the pianist; they can in many cases be studied from photographs when it is impossible to afford the time for travel. The following suggestions may be found useful, and will explain a few of the more acute questions which occur in general practice.

Choose simple objects for practice, such as doors, open and shut, in strong sunlight, with possibly a small projecting hood which casts its shadow over the brickwork and woodwork of the door frame.

Windows offer similar effects, both in casement and sash frames, while a small balcony window gives excellent contrast in materials, particularly those possessing wrought-iron balustrades.

Sketch the shape of shadows and form lightly first—mass in the darkest tone of shade, with a soft pencil (3B), to secure the "pitch" or key of the surrounding tones.

Do not point the pencil for general work, but allow flat facets to form with the strokes; use flat for mass effects and fine edge for detail. A lot of work can be carried through without touching the lead of a pencil. Experiment with various papers. Work with several grades of pencil, *always* working from dark to light in order that the subtle distinctions of tone may be more easily appreciated. This varied use of pencils should be made into a "keyboard" exercise, and the qualities and possibilities experimented with and kept for reference; many of these points apply to pen line work and can be equally well translated in this medium.

Architectural Design

By T. P. Bennett, F.R.I.B.A. and T. E. Scott, F.R.I.B.A.
Revised by T. E. Scott, F.R.I.B.A.

Chapter I—PRINCIPLES OF DESIGN

Introduction. Architectural design is the crystallization into complete form of the many factors which are involved in the production of fine buildings. It is a process which provides for all of the requirements—artistic, structural, and economic—of the buildings required by a civilization. This process is so much dependent upon individual taste and selection, upon individual and even national points of view, that it is impossible to prescribe a clearly defined procedure. Rather is it the intention of these chapters to suggest certain lines of thought which may with advantage be developed by students of architecture.

Architectural design is more than the mere drawing of the decoration of buildings. Although drawing is the architect's method of expressing his intentions, the process of design requires, besides the ability to draw, great technical knowledge and artistic appreciation, and a very substantial measure of imagination and common sense.

Architectural design is largely a matter of selection, compromise, and adjustment: each factor must be given due consideration and be properly provided for, but constant care is necessary lest the excellence of any one feature is obtained at the expense of another, thereby sacrificing the perfection of the whole for that of one part. All buildings are affected by the artistic, structural, and economic considerations, but in varying degrees. It follows, therefore, that the proper consideration of each of them will produce various shades of architectural character and involve various directions of approach towards solution.

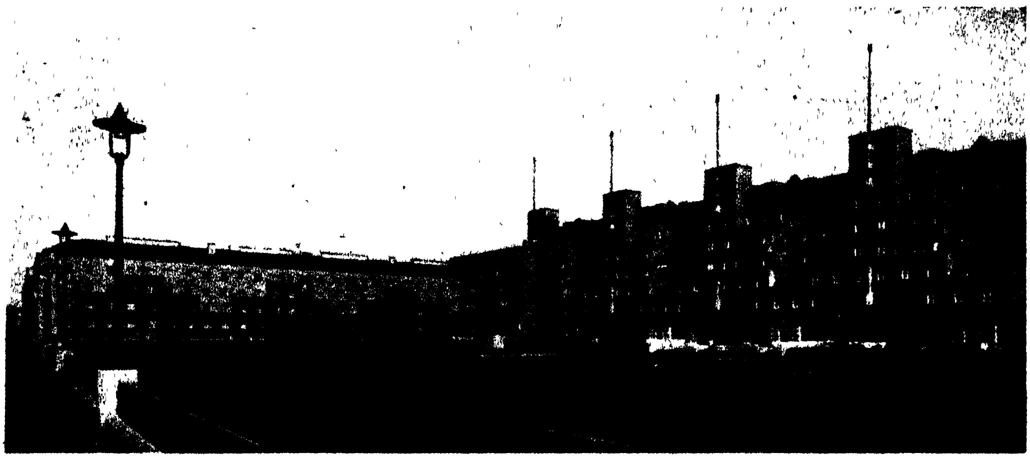


Fig. 1. The Karl-Marx-Hof, Vienna

For example, the housing scheme illustrated in Fig. 1, while in the main concerned with the provision of a large number of flats for small families, has been visualized as a single project of gigantic proportions. Its ultimate form has been governed by the desire to provide large open spaces, with the buildings consistently large in scale, the identity of the individual flats being merged into the wider issue of providing an impressive building. In Fig. 2 the building is the result of the planning of a strictly utilitarian nature, with the imposing mass of

the building growing readily out of the irregular plan form demanded by the type of building. The effective massing is by no means accidental, but the architect has not allowed the practical requirements of individual rooms to be suppressed by a preconceived idea of elevational treatment.

The design of a building, therefore, is the outcome of the careful study of the attendant

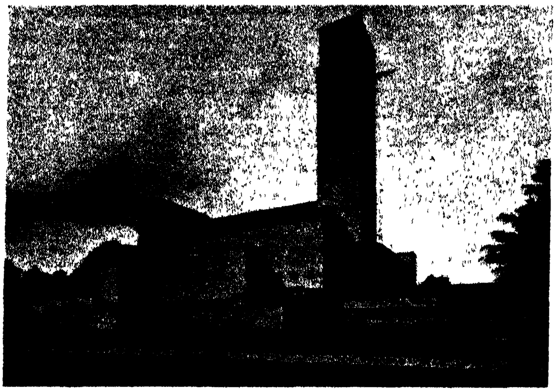


FIG. 2. TOWN HALL, THELVERSUM

conditions in a problem. The knowledge required by an architect to enable him to solve a problem is very varied and extensive. Artistic ability of the first order is essential: the power to draw as rapidly and faithfully as the mind conceives; to visualize the intended building and give it good proportion and pleasing detail. It is desirable to have a knowledge of the works of the past as well as of the present, in order that inspiration may be drawn from them, not merely in detail and ornament, but in character, which is the real essence of architecture.

The architect must have a thorough understanding of the general requirements of modern civilization so that his buildings may be efficient in their services. He must possess a sound knowledge of all methods of construction and their relative costs and qualities, for not only is it essential that his buildings should be structurally sound, but that their costs should always be consistent with their economic values.

Finally, an appreciation of legal matters is important in order that clients may be advised upon the many problems connected with the purchase and leasing of land and the framing of contracts, while an acquaintance with the various building acts and by-laws, both legally and technically, is indispensable.

The study of buildings will show that the determining factors in architectural design may be classified as follows: *the requirements of the programme ; the site ; climatic conditions ; cost ; construction ; and character.*

These factors are by no means disconnected, but will be found to be closely inter-related as soon as an architectural problem is considered, although, for purposes of study, separate consideration is desirable.

THE PROGRAMME. By this is meant the functional requirements of the proposed building. These consist primarily of a schedule of the accommodation and a statement of the function or service of the proposed building. They may be drawn up by the promoters of a building scheme, or may be the result of an intelligent and tactful cross-examination of the client by his architect. It is essential that an architect should make himself thoroughly acquainted with the ultimate working of the building he is to design, and, in the case of a domestic building, with his client's social and artistic outlook.

The requirements of various types of buildings will be dealt with in detail later, but it may be well to consider this aspect of the requirements of the *programme* from another point of view. Tradition, custom and, in some cases, functional requirements, have given a marked character to some types of buildings. This is clearly the case with buildings of a religious nature and those of civic importance. So many buildings serving similar purposes have been built in the same style or manner that they have acquired from their architectural modelling a certain character or expression of function. This character is certainly something to be aimed at and should, when desirable, be anticipated and manifested in the development of the plan which grows out of the problem.

Besides providing rooms of sufficient area and convenient shape and in the proper sequence, it is also at times important to effect certain modifications so as to produce interesting and impressive interiors. In some cases, as in most types of auditorium, the section of a building or room is of equal importance to the plan form.

The importance of these factors is clearly evidenced in Fig. 3, which illustrates the long section of a theatre. Here, it will be seen that the essential conditions are the provision of an adequate stage which may be seen by the whole of the audience seated in the various parts of the auditorium: in addition, provision must be made for the projection of pictures from the bioscope

room *B* to the screen, and this in turn must be so placed in relation to the audience that the picture is not distorted from any seat in the auditorium.

It will also be noted that the slope of the galleries must be such that the sound waves from the orchestra *K* have a direct path to each member of the audience.

Within these limitations, the building is conceived in plan and section simultaneously, both being modelled so as to assist acoustically, and also to provide pleasing shapes. The structural problems of such a building are considerable, and usually take precedence over the planning of the smaller elements of accommodation which, in the section illustrated, consist of the various bars *C*, *E*, and *H*, and staff room *D*.

The limitations of the site in the building illustrated compelled the placing of the bar and lounge in a basement, and also restricted the size of the entrance hall *F*. The various ventilating trunks are provided within the shaded areas, and the plenum chamber *M* is so constructed and located as to prevent the passage of sound to the auditorium. When it is appreciated that these and many other factors are not merely necessary for efficient practice, but also insisted upon by public authorities, the complexity of such a programme will be appreciated. It is an essential part of an architect's training that he should analyse the various types of buildings, and become acquainted with their detailed requirements, for these must always have greater controlling influence over design than the mere creation of interesting elevations.

SITE. The nature of the site of a proposed building is one of the most important factors in architectural design. The size, shape, and contouring or levels of the site will obviously influence the shape of the building. The *aspect*, or the relation of the site to the points of the compass, and the surroundings of the site, will determine the direction in which the various parts of the building will have to face.

The site and its influence on architectural design will be dealt with fully in a later chapter.

CLIMATIC CONDITIONS. The influence of climate on architecture is dual. In the first place there is the obvious need for the adequate lighting and ventilating of buildings, and secondly the need for the protection against the weather.

Generally speaking, the temperate climate of this country does not impose very serious restrictions upon design, and normally the problems of lighting and heating are readily solved, except in the case of buildings on expensive and enclosed sites, where financial considerations may compel the provision of greater floor areas than can be given adequate natural lighting.

It will be appreciated, however, that in architecture of a traditional character the window openings have frequently been on the small side and that the desire to provide large areas of glass may result in increasing difficulties in the warming of rooms. It is desirable, therefore, that the design of windows should always be accompanied by the careful consideration of other problems involved.

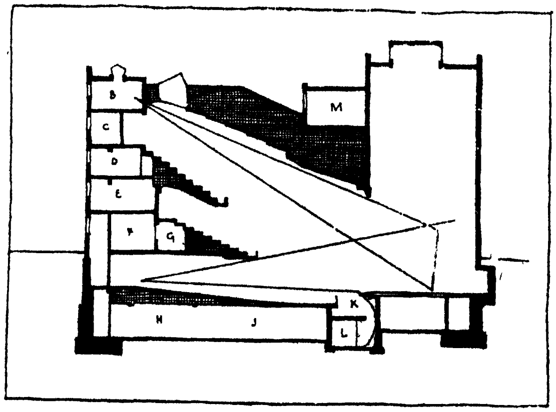


FIG. 3. SECTION THROUGH A THEATRE

In the study of historic architectural features it will be found that climate has exercised a greater influence on them than may at first be apparent. Reference to this aspect of design will be made in later chapters.

COST. The limitations which the cost of a building sets upon its design are at once obvious. It is important, however, that the question of cost should be considered from all points of view, having in mind not merely the actual cost of the labour and materials involved in construction but also the cost of the subsequent upkeep and supervision of the occupied building. It must also be appreciated that the very high cost of some sites will make a rapid form of erection essential even although this may involve a more expensive type of construction.

CONSTRUCTION. It is not within the scope of this section to consider in detail the construction of buildings, but the importance of construction in architectural design cannot be exaggerated. It is hardly necessary to emphasize that the first essential in all designs is that they must be

buildable, and that in the best designs the construction will be logical and straightforward. While it is true that scientific knowledge permits even the most ambitious architectural conceptions to be constructed, it should be constantly remembered that the perfect building is the one in which the planning of the required accommodation automatically provides for logical construction. The study of the best historical architecture will show that each building is contained within the proper structural limits of the materials used, and that the structural form provides the basis for the architectural decoration. Many traditional forms and features have been developed from structure, and it is from this point of view that they should be studied. It has truthfully been said that the practical and artistic requirements of a programme should be readily constructable, and that subsequent enrichment should beautify this structural nucleus but never hide it.

CHARACTER. Although the satisfaction of practical requirements is usually the primary object of buildings, it is the deliberate effort to create beauty that may translate building into architecture. Beauty in building is not merely a question of style and decoration, nor of ingenious construction and fine craftsmanship. It is a blending of qualities which are almost incapable of adequate description. In some cases we may be satisfied by certain characteristics, and subconsciously adopt them as standards by which we may judge or create other buildings. This satisfaction is not properly derived from preference for any one style, but results either from the presence of certain positive qualities or the absence of features which are disagreeable. These positive qualities may consist primarily of suitability of character, a general orderliness of the building, an appearance of stability, pleasant colour, and harmony with surroundings; while closer examination may reveal a consistent arrangement of shapes, proportions, and detail. Fine architecture cannot be produced by the deliberate application of any rules of design, but conversely, if architecture is examined critically from a consistent point of view it may often be found to suggest certain principles of design. These are by no means capable of application to all buildings, for in some cases they can be made to contradict each other. As a rule, however, it will be found that if design is created from, or judged by, a reasonably consistent point of view it will at least be satisfactory. Architecture that is really great seems generally to extend beyond any such analysis and can only be looked upon as the inspiration of genius.

Process of Design. It may therefore be considered that architectural design is a process of selection which is regulated by personality and inspiration. The process will commence with the careful study of the intended building in the light of the various factors which have been enumerated; it need hardly be emphasized that this study can only be made by one who has both knowledge and experience. The vital predominating factors will emerge from the sometimes confused collection of data and factors, and will become the controlling elements in the evolution of the first "visualization" of the solution. Many solutions may offer themselves for consideration, until finally it will be possible to indicate the main lines in the intended structure.

The word "structure" is used here with special significance. Architecture is concerned mainly with the design of enclosed volumes or spaces, and finds expression in the method of construction and decoration of the structures forming the enclosures. It will be pointed out in a later chapter that in most phases of architectural evolution buildings exist primarily as structural forms or skeletons, and that the recognized characteristics of the various styles result from the decoration of the structure. It will also be found that although decorative forms vary considerably, there is only a limited number of types of structure. The size and type of building, the materials available, and economic considerations will determine the type of structure to be adopted, and "visualization" should normally occur as a logical building form rather than as an abstract shape. Once the broad lines of the design have been determined, it is necessary to study in detail the various parts of the building, both separately and collectively. Apart from the practical considerations of planning and construction, there will be the desire to give character to the building. This may be achieved both internally and externally by the relationship between the various parts of the building, by the modelling of wall surfaces, the proportioning of details, and the use of colour and texture. It has already been stated that there are no precise rules which control character, but the following "Principles of Design" are given to suggest an approach to the creation of expression of character in buildings; to give them that refinement, grandeur, gaity, solemnity, vigour,

and restfulness, or other qualities that may characterize their purpose.

These principles are essentially the expression of a personal and individual point of view; they are for the most part related to examples and diagrams based upon traditional models, which generally appear to afford easily recognizable comparisons and descriptions.

It is, however, important to appreciate that they are by no means exhaustive, nor do they represent the only desirable approach to the study of design.

The study of contemporary and traditional buildings will reveal that those qualities to which reference is made may be achieved in countless ways, and that although the use of new materials and the satisfaction of new needs have resulted in new forms, and even in new fashions, the aesthetic qualities remain the same. Indeed, the study of old and new buildings in almost any town will show that examples can be found from which to formulate principles of design.

It is through this critical examination of buildings or designs that the student may first of all discover why he admires this or that building, and having founded his judgment upon careful thought rather than upon hurried impressions or current fashions, he may develop his own creative ability and learn to impart to his own designs those qualities which he finds agreeable in the work of others.

Principles of Design

The character of various types of building is very largely the result of tradition, and tradition may be either historical, or, in the case of buildings to suit modern requirements, may be very quickly established by a decided uniformity of characteristics over a short period. Character will be found to be created usually by certain qualities, of which the one most frequently referred to is *proportion.*

Proportion. Proportion may be considered in relation to almost every aspect and detail of architecture.

In the first instance, it is essential that the relative importance of the intended building must be appreciated, and the design developed accordingly. This aspect is usually considered as *scale* and will be dealt with later. Proportion may also be described as the relationship between the parts which constitute a complete unit; thus the relationship between the sides of a rectangular door or window may produce a square opening, or one which is tall and narrow; the dimensions of a room may produce a lofty and impressive apartment, or one which is low and depressing. Many theorists have produced geometrical rules for proportion, and have illustrated their theories with certain coincidences in antique architecture. These theories are interesting and frequently of some use in modern practice, in that the consistent application of a theory will often give uniformity of proportion throughout a design. This, however, is not always desirable, since due prominence may frequently be given to one feature by the skilful contrasting of the proportion of other features.

Certain more or less definite proportions are usually associated with the historical styles; for example, the Orders of architecture, when used in a traditional manner, should always conform with the generally accepted traditional proportions, while door and window openings which are based upon historical models for their detail should also have similar proportions. In the study of contemporary work, it will be found that modern construction usually permits much wider openings and longer spans than were possible previously, and also that columns and stanchions of steel and reinforced concrete need not be as thick as those that were constructed entirely of brick and stone. In these circumstances, unless the building is deliberately created in imitation of one of the historical styles, there is no reason to adopt historical proportions in the design of door and window openings and the spacing of columns. Each case may be determined on its merits, after due consideration of the practical requirements.

To appreciate proportion it is necessary to study fine architecture, and thereby cultivate good taste, for a sense of what looks well is the surest criterion for proportion.

There is, however, one aspect of proportion which appears to be decisive. The proportions which go to make a shape should be definite. A square should be an exact square and an oblong definitely so; similarly, there should be no hesitation in circles and elipses, for shapes which might be either will rarely give satisfaction.

Throughout the chapters that follow reference will be made to the significance of proportion in the design of façades and of various features and details.

Scale. Proportion must also be considered in its broadest sense.

In any work of architecture it is not only necessary to study the relationship between the

component parts, but also the proportions between the building and other comparable objects.

This is known as *scale*. Scale, more than anything else, will determine the character of a building.

In the design of a building in which there are big parts, such as a railway station, a theatre, or a bank, the external motifs should also be big, so that they may express the truth of the building (see Fig. 4).

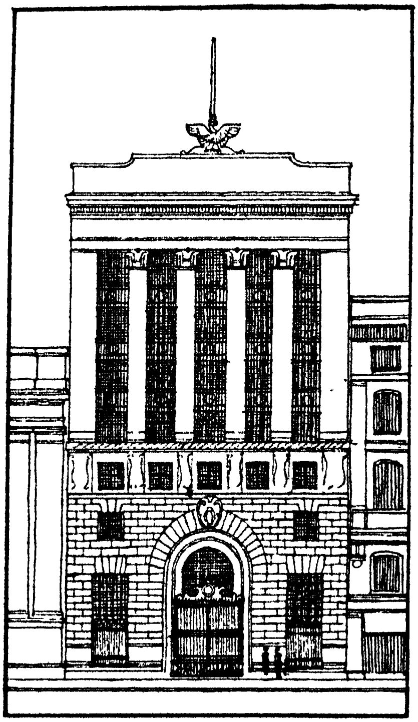


FIG. 4. AN AMERICAN BANK BUILDING

The same scale should be maintained throughout a building, but always there must be some readily appreciated feature which will give the general scale its full value. Referring again to Fig. 4, it is seen that the upper floors are united in an " order " which maintains the scale set by the entrance, but that the impression of size is created by comparison with the single intermediate windows.

Simplicity and fewness of parts will convey an impression of bigness which is known as large scale; a multiplicity of elaborate parts—small scale. It is essential to grasp the importance of the programme and treat the elements accordingly, but a building should never be overloaded with small parts or broken up into small features. It must be allowed to look its size.

Scale is influenced greatly by environment; if any object, which is normally seen and used indoors, is examined in the open air, the result is surprising. Spaciousness greatly reduces scale. The Arc de Triomphe, in Paris, is worth study; its huge size is not realized without careful comparison with familiar objects, such as the human figure. But the edifice is in scale with its surroundings; it dominates without overpowering. Scale, however, must recognize human proportions. Whatever the requirements of beauty, the dimensions of useful elements, such as steps, doors, and balustrades, must always be consistent with their utility.

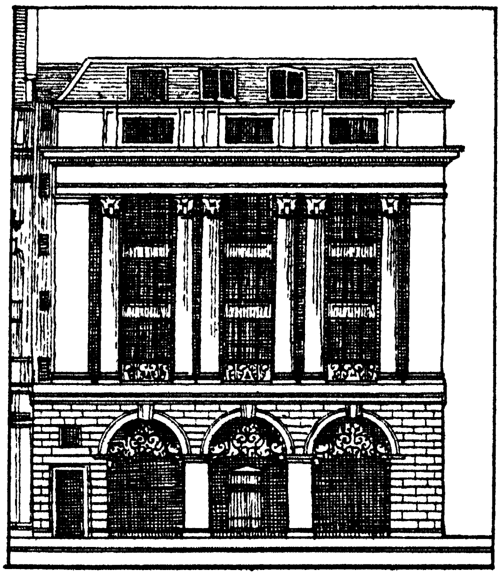


FIG. 5. THE WOLSELEY BUILDING, PICCADILLY
(*W. Curtis Green, F.R.I.B A., Architect*)

Architecture must be well mannered. The civil importance of state, municipal, and religious buildings must be recognized, and the commercial or domestic building so designed in scale that it is given its proper position of civic precedence.

Construction must govern design, for if a building expresses its construction truthfully, it will surely have the appearance of stability and repose, which are two of the great essentials in design.

Architecture is only just emerging from a period of transition in construction. Steel and reinforced concrete construction have developed rapidly, and those architectural forms which have grown out of brick and stone construction are not given up without reluctance.

Perhaps this is natural, since traditional forms have, through long usage, acquired certain characteristics which are used to give expression to architecture. If the programme appears to call for expression in one of the historic styles, inspiration may be drawn from that source without hesitation, but in spirit as well as in detail. Fig. 5 illustrates the use of classic motifs

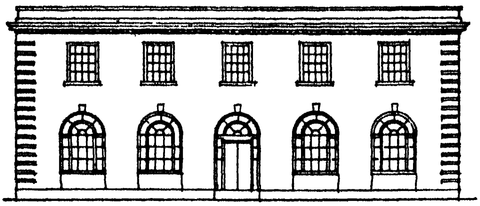


FIG. 6. A FAÇADE DEFINED BY QUOINS, CORNICE, AND PLINTH

in a steel-frame building, in which all of the elements proclaim the structural function which their positions in the design justify. It is also interesting to note that although the proportions of the upper windows are contrary to those

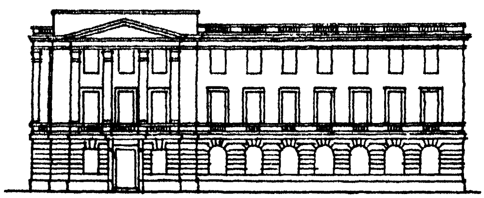


FIG. 7 AN ASYMMETRICAL FAÇADE

usually associated with classic architecture, they are lost in the more pronounced proportions of the openings between the columns.

Unity. Beauty in architecture depends largely upon *unity* of form. The various elements that go to make up a building must be so related as to produce a unified composition. There must be no hesitation between the elements; the most important must always be in the right place, and be given its proper degree of prominence.

To express unity, a building must give the impression of completeness, a quality which is essential for the expression of stability.

Regardless of any hidden construction which may render such expression unnecessary to the actual stability of the structure, the artistic sense will require these refinements, both for the expression of stability and of completeness. In the absence of a generally understood term, this may be called "definition."

It is seen in Fig. 6 that the component parts of the façade are unified by the use of the crowning cornice and the rusticated quoins, which properly punctuate the building, announcing definitely its completion.

Symmetry. An expression of unity may result from a regular or geometrical disposition of the elements on either side of a centre line; this is called *symmetry*.

Symmetry is often desirable, but it must be

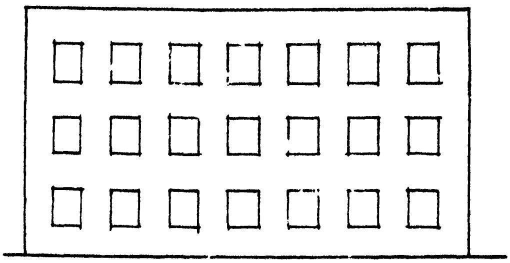


FIG 8. THE ABSENCE OF DEFINITION AND INTEREST

intelligent; it must not be sought if the programme requires elements of dissimilar shape and size, which cannot be grouped into equal masses without destroying their proper functional sequence. In such cases, an *asymmetrical* composition will provide the proper solution of the problem. This does not imply the entire absence of a focal point or of balance in the various parts, but, as will be seen in Fig. 7, a composition of unequal masses, with the centre of interest on the axis of the main mass.

An asymmetrical composition should not be created for its own sake, but should be the logical outcome of the conditions of the problem: an irregular site, or special peculiarities of accommodation may logically enforce such a solution, as in Fig. 2.

Harmony. Finally, the expression of unity must be maintained by a consistency of stylistic treatment throughout the composition, with a harmony of proportion and scale in all features.

Harmony, however, must not be confused with monotony. It must result from the proper proportioning of contrast of shape, size, texture; verticality and horizontality; light and shade; solids and voids; plain and decorated surfaces. The proportions must never be hesitating; one must always clearly dominate, with the other acting as foil. There must always be sufficient variety to bring interest, but care must be taken to avoid too many contrasts, for they will break up a composition, or defeat their purpose by being monotonous.

St. Paul's Cathedral illustrates how a dome may dominate a composition, largely by virtue

of the contrast of its shape with the rest of the building; but in St. Mark's, Venice, the oft-repeated dome brings a restlessness into the composition.

Again, in variety of texture or material, sudden or frequent changes must be avoided. The study of the brick and stone work of Wren at Hampton Court and elsewhere will show how logical is his use of material: the stone bases and cornices linked up by the use of stone quoins, and dressings to windows in the intermediate parts.

FIG. 9. A MAUSOLEUM: NEW YORK

For the treatment of voids and solids, the finest works of the Gothic and Italian Renaissance periods are a valuable source of study.

There should usually be a decisive predominance of one or the other. In the diagram (Fig. 8) a façade, with equal divisions of void and solid, shows how dull such a composition may be; this diagram illustrates also the feeling of incompleteness and lack of stability through absence of "definition."

Light and shade are related to voids, but result chiefly from the modelling of wall surfaces. The positions of the main shadows must always be very carefully considered, since they will break a façade up into a number of separate elements which must then be resolved into unity. It may be logical to express the plan with breaks in the elevation, and then, if the parts of the plan are properly proportioned, the resultant façade will usually be satisfactory.

The most important features should always have the strongest shadows. It will be seen in Fig. 9 that the pilasters have only little projection, but the entrance, being the focal point, is deeply recessed.

Ornament. The considerations of *ornament* are far-reaching. So many of the once structural elements are now used as decorative motifs, that almost all of the features, except walls and openings, might reasonably be considered ornamental.

It is reasonable, however, to use features which have decorative value, so long as they are properly placed, and serve some definite purpose in the composition.

Decorative panels under windows may enhance their proportions; a carved keystone will give emphasis to an important door opening.

Existing architecture will suggest countless examples of ornament, but care must always be taken that decoration does not destroy the apparent structural function of a feature.

Essential Elements. These remarks have touched only upon the fringe of architectural beauty. The student must increase his knowledge by study. The constant critical analysis of buildings, or photographs of buildings, is the only way to acquire the ability to create fine architecture.

The essentials of good design may be summarized as—

1. Faithful adherence to the programme and its attendant requirements.
2. Faithful expression of the programme.
3. Stability, both real and apparent.
4. Beauty, resulting not from astonishment at mere size or ingenuity, but from the happy infusion of interest and variety into the elements of a composition, always unified by harmony and proportion into a single idea.

To crystallize design into elements capable of practical application, it is necessary to consider the subject in three sections.

First, the study of the elements of architecture, such as structural method, walls, doors, windows, and the orders, etc., not merely as archaeological research, but as an analysis of their origin and subsequent development as functional elements in design.

Secondly, the study of the elements of composition, such as façades, rooms, communications, porticos, etc., and the principles governing their composition into the plan, which is usually the fundamental element in design.

Finally, the study of the requirements of the various types of buildings required by our modern civilization.

Chapter II—THE ELEMENTS OF ARCHITECTURE

Structure. It has already been suggested that inspirations or ideas should offer themselves as structural forms. The designer must have knowledge of the principles of various forms of construction to such a degree that he will instinctively think only in terms of logical construction. Besides having a working knowledge of the technical details of each system, he must appreciate their economic possibilities and limitations. Space will not permit of a complete survey of the various forms of construction that have been used throughout the ages, but the student is strongly recommended to make a careful analysis of characteristic buildings of each phase, and to prepare diagrams similar to those which appear in this chapter in order to illustrate the development of structural forms. Early types will be found to include those with thick walls enclosing small chambers, the dimensions of which were limited by the type of material available for the roof covering. The desire to create larger apartments led to the introduction of intermediate supports. These systems are diagrammatically illustrated in Fig. 10; other interesting examples are to be found, particularly among the temples of the Egyptians. The most important development in structural form was the introduction of piers or columns, with beams and trusses instead of the solid continuous wall and flat roof or barrel vault. Both types of construction are evident in modern work and represented by the steel-framed building on the one hand and the building with structural walls on the other. The use of stanchions and trusses usually involves the planning of a building in a series of regular bays. This will be discussed in detail later. The evolution of structural methods may be traced through the work of the Greeks, in which the limitations of the lintel form of construction will be obvious.

In Roman work the introduction of the concrete vault made possible the creation of large covered spaces, and subsequently the development of the cross vault reduced considerably the area of supports. The study of the monumental buildings of the Romans will show that this form of construction dictated definite types of plan-form, and consequently building shapes.

The study of medieval work from the early Romanesque to the late Gothic will show similar developments, although in different materials and resulting in different architectural forms. The structural significance of the vault, the pier, and the buttress has been referred to in the chapters on the history of architecture.

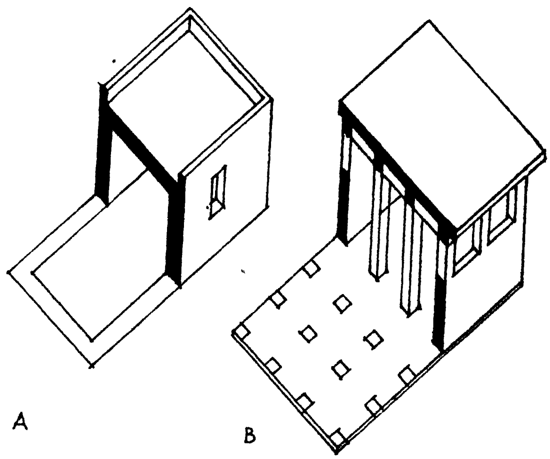


FIG. 10. EARLY TYPES OF STRUCTURE

Generally speaking, the early buildings of the Italian Renaissance do not usually show this same relationship between building forms and structure, except in those churches and other buildings which have vaults and domes. The plan and sections of many of the great churches and cathedrals of the Renaissance provide a very interesting study, and show that in most cases there was a very skilful balance of vault against vault, and arrangement of cross walls to resist important thrusts from domes and arches.

Subsequent to the Renaissance, and up to the present century, very little progress was made; even the introduction of iron and steel construction did not in the beginning bring about fundamentally new forms of construction, but the iron and steel members were used as a skeleton to reinforce a structure conceived on classical lines. During this present century, new forms of construction have asserted themselves and have brought about new building forms. Modern buildings should be carefully analysed from this structural point of view, and

it will frequently be found that the external and internal forms grow logically out of constructional necessity. In Fig. 11 (*A*) it will be seen

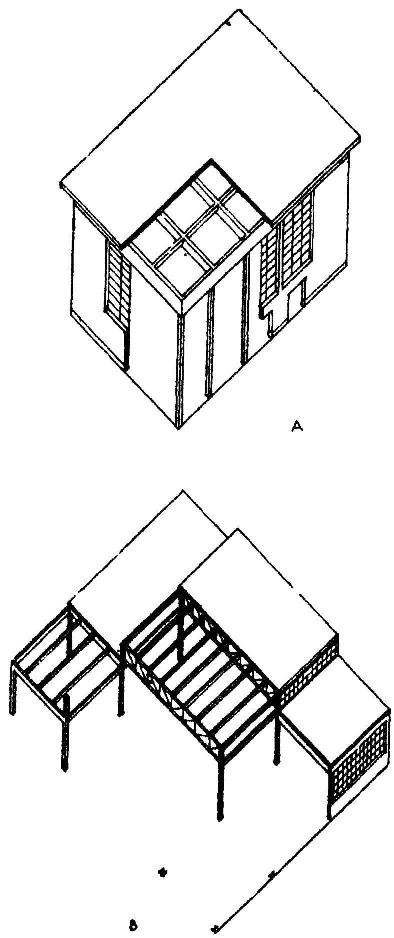


FIG. 11. MODERN TYPES OF STRUCTURE

that the building consists of a skeleton or frame, designed to use economically standard steel sections, the ultimate placing of windows and doors, and the design of the ceiling being determined by the position of these structural members. In Fig. 11 (*B*) a factory type of structure is illustrated. This results from a desire to create large unobstructed areas within certain economic limits. In this connection it is frequently found that bays of 45 ft. by 30 ft. are economical, but when large areas are covered such as the one in Fig. 11 (*B*), the problem of natural lighting becomes important; the study of modern factories will reveal many interesting arrangements.

Fig. 12 (*A*) shows a comparatively recent

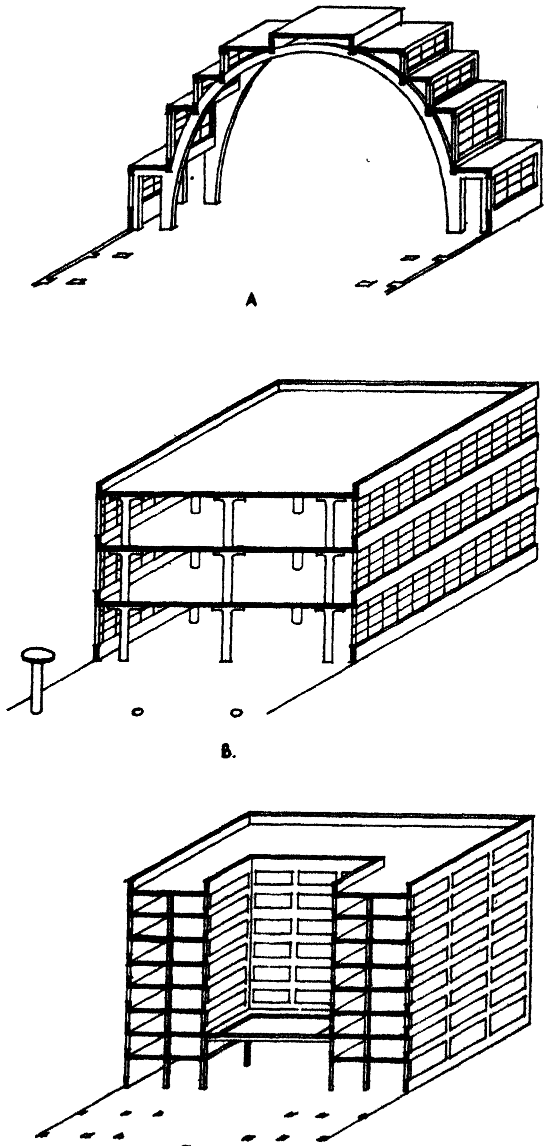


FIG. 12. MODERN TYPES OF STRUCTURE

A. Place of Assembly
B. Industrial Building
C. Office Building

development. This form originated from the scientific study of reinforced concrete, when it was found that an arched form of truss approximating to a parabola provided a more economical form of spanning a space than was possible with

vertical columns and a horizontal beam of the same height and span. The arrangement of the purlins and clerestory lights, as shown in the diagram, is a logical solution in the provision of a roof and adequate windows. Interesting examples may be seen in various parts of the country, one of particular interest being the Horticultural Hall, London. Other experiments have evolved the mushroom form of construction illustrated in Fig. 12 (*B*). This may consist of columns at about 20 ft. to 24 ft. centres, each column spreading at the top to a circular cap of about 6 ft. diameter. This cap supports a floor slab without the use of beams, and has been found useful in buildings of the factory type. It will also be seen that the external wall or screen of the building is supported on the floor slab and may therefore consist of a continuous range of windows on all sides of the building.

Perhaps the best known form of construction is that in which the building is divided into small bays or cells by a series of stanchions and girders. While it is possible to construct steel girders of almost any span in buildings similar to the one illustrated, a maximum of about 24 ft. will usually represent the most economical use of steelwork. The building form illustrated is a common type frequently used for offices and similar buildings; where the floor heights are about 10 ft., the width of building between external walls is limited, owing to the need for providing adequate natural lighting. The central well provides light to the upper floors, and the space is usually occupied on the ground floor by a large important room which is top-lighted. Fig. 13 shows a novel form of construction in reinforced concrete. In shape, it is reminiscent of the chapter house of many medieval cathedrals, while structurally it is the application of the mushroom form of construction to a large scale, with the addition of a steel or concrete frame around the perimeter. These examples are but a few among the many which may be used in the solution of modern building problems. They represent the logical use of materials and should be understood by the architect, so that he may employ them intelligently and logically in the solution of his problems.

Walls

It will be appreciated from the foregoing that walls may exist as structural supports to floors and roofs: they may also occur only as protective screens between pillars or stanchions, and as isolated walls.

Isolated walls are designed primarily to resist earth or water pressure. They are usually about one-fifth of their height in thickness, and in some cases battered, or they may consist of a thin wall with buttresses or piers at intervals.

Such features as plinths and cornices contribute to the artistic effect of isolated walls, while buttresses, piers, and " chaines " give both structural and aesthetic relief to long unbroken walls. A balustrade frequently surmounts the wall, both as a useful protective feature if the

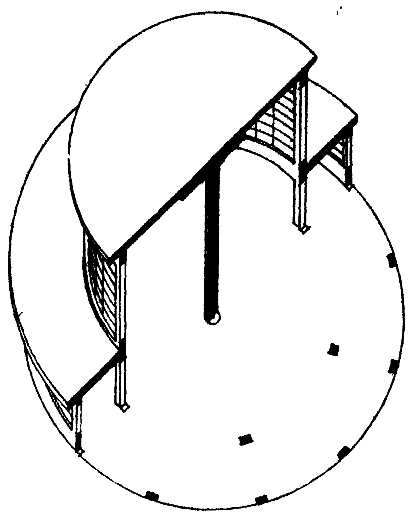


Fig. 13. Structure in Reinforced Concrete

ground is high on one side, and as an architectural embellishment. All of these features will be referred to later.

Structural walls are primarily space enclosing elements which form rooms, or collections of rooms, in a building ; consequently their form and dimensions must first be determined by the requirements of the plan.

The wall has been the most important element in the evolution of architecture, and it is therefore important to study its development and use throughout the ages; even in modern work where the wall is no longer functioning as the main supporting element, it is frequently designed to imitate historical examples: it is therefore essential that its decorative treatment should be controlled by the same structural and other considerations which governed the originals.

The first consideration in the design of the wall itself, as part of a composition, is its thickness. This will be determined by the

requirements of *construction, climate, effect,* and *decoration.*

Construction. The study of constructional methods throughout the ages will show that in early work there was a great timidity and waste in construction, but as knowledge increased and

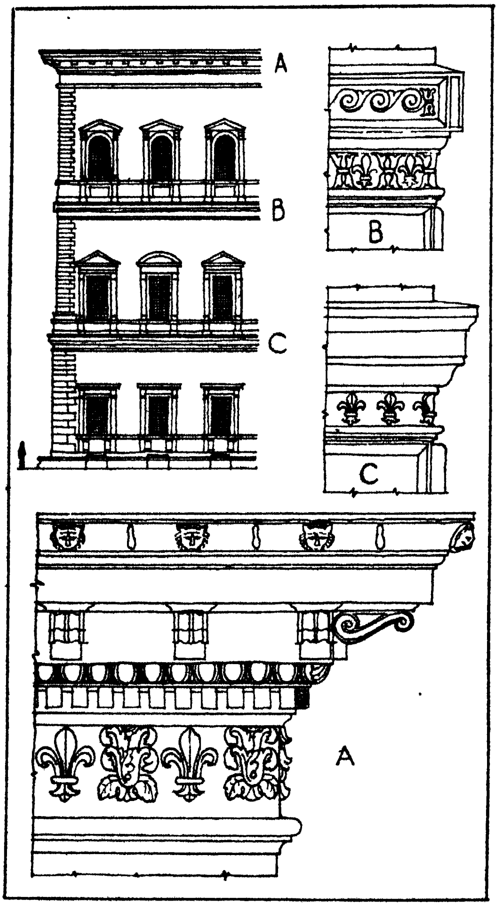


FIG. 14. FARNESE PALACE, ROME
Part elevation and details of main cornice and strong courses

the advance of civilization abolished slave labour, walls and other supports were decreased in thickness, thereby economizing in material, money, and space. A comparison between the Hypostyle Hall at Karnak, the church of St. Sophia at Constantinople, and any modern factory will show the respective areas of space occupied by walls and supports to be 36 per cent, 16 per cent, and something less than 10 per cent of the total area of the building.

Walls were generally built of a number of relatively small blocks bonded together; the importance of bonding is known to the most junior student of architecture.

Nothing influences the design of a wall so much as the material. Ashlar walls should have regular courses because each stone is highly finished. In walls of different materials, such as

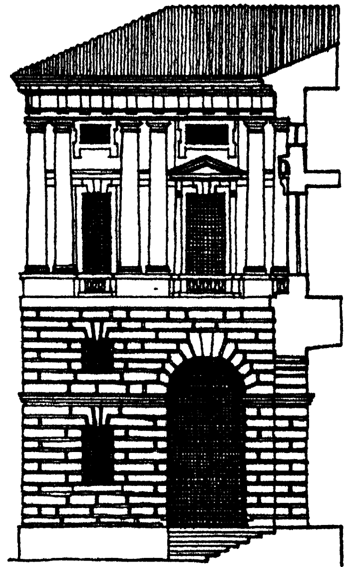


FIG. 15. GRAN GUARDIA, VERONA

random rubble with ashlar dressings, or brickwork with stone quoins, bond will be an important consideration. There may be vertical courses of dressed stone or "chaines," with filling of the rougher material, or horizontal lacing courses of brick or large stones in a rubble wall. In all cases, these variations must have some constructional significance in their position and treatment, and the two materials must be properly bonded together. Stones which are used in brick walls must equal a number of brick courses in height, and a brick dimension in length. Rustications should preferably consist of an odd number of courses with long stones at the top and bottom.

In any one building there may be walls of varying thicknesses. External walls will usually be thickest, since, besides protecting the inside of the building, they have to resist the oblique thrust of a roof, and the eccentric loads of floors. Internally, it is necessary to distinguish between partitions and load carrying-walls. The latter will be required to support loads from floors, and to resist forces which tend to overturn them, such as oblique thrusts from vaults and

arches. In a good plan, these oblique forces will be resisted by skilfully arranged cross walls of normal dimensions or by the balancing of one vault or arch against another. Many of the domed churches of the Renaissance show evidence of planning governed by the construction of the dome.

The actual dimensions of walls will be determined by building laws, or by scientific calculations. They must never be guessed, but as soon as the safe minimum has been settled, increases may be made to obtain effect.

Stability may be attained by the use of piers or buttresses at regular intervals. Once the general proportions of these are settled, their actual dimension, if in brick walls, must be a brick dimension, in order to avoid waste and unnecessary labour.

The arrangement of external and cross walls should always be straightforward, in order that they may be bonded together satisfactorily.

EFFECT. A thick wall is frequently required for sake of appearance. In modern steel-frame buildings, although thick walls are not usually essential for constructional purposes, they are sometimes used in special positions to give depth to door and window openings in order to create a rich and monumental feeling. This is quite reasonable when economy is not of primary importance.

Walls at the base of a building are often thicker on account of the architectural treatment of the walls above. Pilasters, or free or engaged columns in the upper part, will require considerable thickening of the wall below to support them. This point is illustrated in Fig. 15; there are typical examples in London at Somerset House, the Banqueting Hall, and the Government Buildings, Whitehall. The use of steel or other hidden construction must not permit overhanging features which do not appear to be supported.

DECORATION. The basis of the decoration of walls is primarily a consideration of construction. Walls must have a foundation or base, of which the plinth is the expression, a containing part or surface proper, and a cornice or other protective crowning feature.

The plinth provides additional thickness which adds to the stability of the wall. Its function must be expressed in its treatment, which should be simple; it should have few joints and bold mouldings. There are many examples of the variety of treatment possible: the stylobate of the Parthenon, the simple deep course of the Panthéon, Paris, and the more elaborate types of the Italian Renaissance; see Figs. 14, 15, and 16. In tall buildings, the whole of the ground floor may be treated so as to suggest a base proportionate to the height of the building, channelled joints and rustications adding to the solidity of appearance.

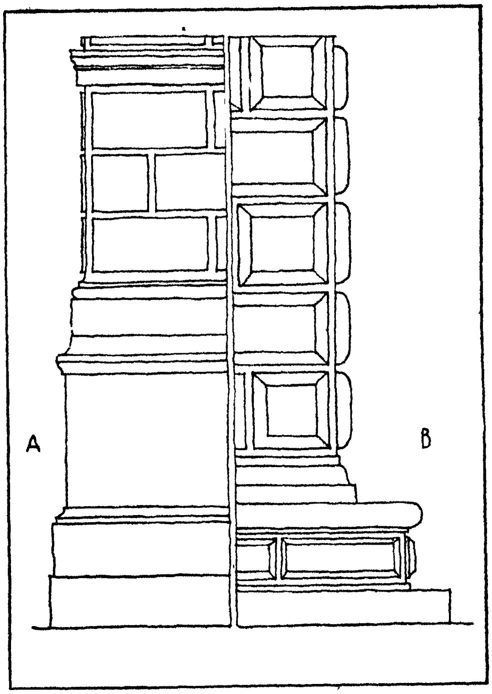


FIG. 16. PLINTHS

A = Cancellaria Palace, Rome *B* = Strozzi Palace, Florence

On the surface of the wall itself, decoration may be introduced by windows, the Orders, etc., which will be discussed later.

Rusticated quoins emphasize the importance of the angle, and are logical as expressions of added stability at an exposed point; see Fig. 14, and many other buildings of the Italian Renaissance. "Chaines" are of great interest when carefully handled. The finest examples may be found on some of the seventeenth-century architecture in France. Fig. 17 illustrates the employment of "chaines" in a pavilion of the Chateau of Balleroy, by F. Mansart.

Horizontal emphasis is obtained by the use of string courses, which should also be used to mark changes in material or surface treatment. When used, they should locate structurally important points, such as floor or sill levels; see Fig. 14.

String courses must always be subordinated to the cornice.

Screen Walls. The design of the wall in modern steel-framed buildings is not seriously affected by structural considerations. Its thickness in such buildings is regulated by by-laws and by the convenient handling of the materials employed. Brick and stone are frequently used, both in a modern manner, and in imitation of historical styles; in addition, such materials as sheet glass, large slabs of reconstructed stone, and sheet metal are used, usually secured to a thin backing of concrete or brickwork.

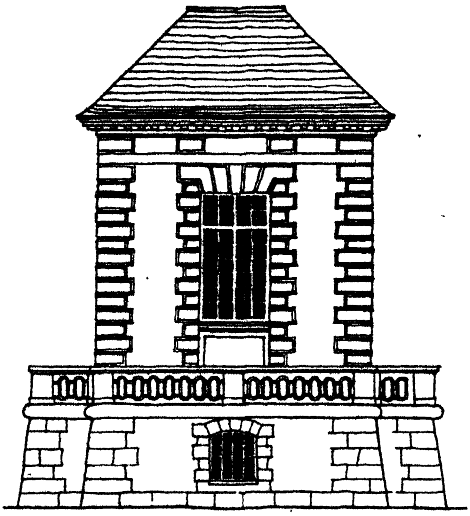


FIG. 17. THE CHATEAU OF BALLEROY
A Pavilion

CORNICES

Although the cornice originated as a protection to the top of the wall, it was developed mainly as a decorative feature. Its simplest form is a stone or other coping, weathered on the top so as to throw off the water, and with a drip on the underside.

In classical architecture the cornice is an important feature: in detail it is similar to those used in the orders, but its height should be proportionate to the height of the building. A frieze may be used but is not always essential. It will be useful to compare the height of the cornice in relation to the building in good historical and modern examples. In London, cornices may not project more than 2 ft. 6 in. over the public way, but if the building is set back from the frontage, greater projection is possible and very desirable in some types of tall building.

It has been pointed out that the cornice is an appropriate crowning feature to a building, but a similar service may be performed by a simple coping or parapet wall (Figs. 2 and 27); indeed, unless a façade is definitely developed and detailed in a classical manner, a cornice is usually unsuitable as well as being costly.

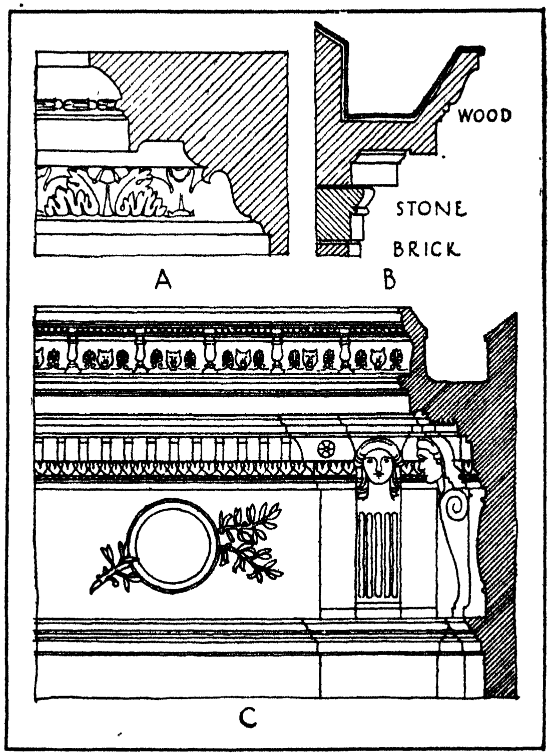


FIG. 18. CORNICES
A = The Clifford's Inn Room, Victoria and Albert Museum
B = St. Benet's Church, London *C* = Palais de Justice, Paris

Types of cornice are illustrated in Fig. 18.

DOOR AND WINDOW OPENINGS

Openings in walls are of two distinct types—rectangular and arched—evolved from the constructional use of the lintel and the arch. In historic architecture, these methods have been employed for small and large openings respectively, but modern methods permit square-headed openings of greater span than is possible with the natural usage of brick and stone as constructional materials.

In the earliest times the lintel was the only method employed in spanning openings. Its

limit was soon reached, and this was one of the controlling features in Egyptian and Greek architecture.

There have been many attempts to overcome this difficulty: the heavy abacus of the Greek Doric Order, the battered jamb in Egypt and Greece, and the corbel under the lintel in Gothic work. None of these methods increased the size of the opening appreciably, but, in the two latter cases, they seriously interfered with the hanging of a door and the framing of a window.

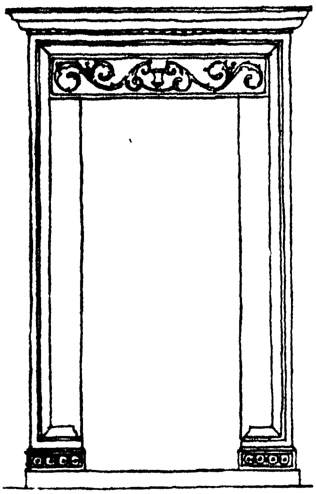


FIG. 19. DOORWAY AT CORNETO

They all serve to illustrate the enormous freedom given to architecture by the discovery of the arch, the origin of which is not known, but is an interesting subject for speculation. It will be well to consider these two types separately, since their construction insists upon different architectural decoration.

Rectangular Openings. In primitive architecture it is not uncommon to find the sill, jambs, and lintel of cut stone, while the surrounding walling is in rubble. The subsequent decoration of those features provides what is known as an *architrave*, the most logical decoration which can be applied to a door or window opening. The next step is the introduction of a cornice to prevent rain from running on to the window. There are windows of this type at the Temple of Vesta at Tivoli, and an interesting variant is shown in Fig. 19, in which the importance of the lintel is accentuated by ornament. Between the architrave and cornice, a frieze may be added, giving a composition capable of many variations. Fig. 20 is one of countless examples.

The subsequent introduction of a pediment may be open to criticism in point of fitness, but since it serves to throw off the rain to the sides of the opening, its use may be accepted as sound. In any case its decorative effect fully justifies its employment (see Figs. 22 and 23).

Greater effect will be given to the cornice by prolonging it beyond the architrave and supporting it on consoles. It is essential that (1) the console shall be far enough away to allow for the bearing of the lintel; (2) the console must not descend below the underside of the lintel; if it does, the lintel itself will rest upon a small unbonded stone; (3) the cornice must project equally beyond the face and side of the consoles; (4) if the bed moulding is deep, the upper member only need run around the console, the remainder stopping against the side, as in the famous doorway of the Erechtheion.

The console may be supported on a plain band or architrave of the same width as the console, thereby establishing a link between it and the wall.

Door and window openings may also be decorated by the use of the orders. There are many excellent examples to be found in the work of the Italian Renaissance.

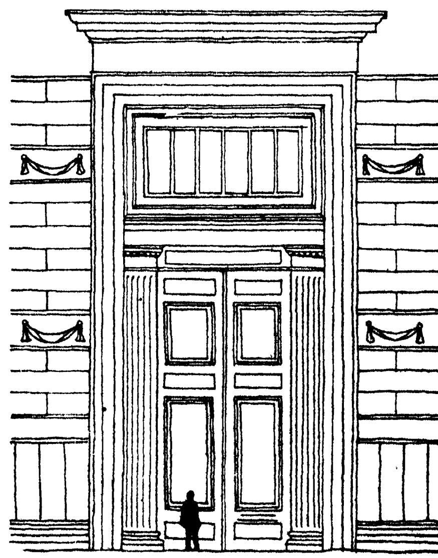


FIG. 20. DOORWAY OF THE PANTHEON, ROME

Rectangular openings with flat arches, having radiating or joggled joints, have been used with much success since the Renaissance (see Fig. 17). The underside should be slightly cambered to prevent the appearance of sagging.

In modern work the use of steel and reinforced concrete will permit very wide rectangular openings. The decorative design of these openings calls for very skilful handling if classical motifs are used, and the depth of the stone "lintel" or arch should always be sufficient to suggest adequate strength without the hidden

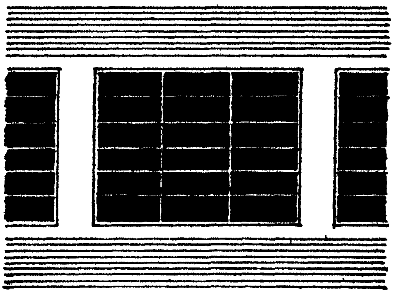


FIG. 21. A MODERN TYPE OF WINDOW

steel or concrete skeleton; if, however, the design is developed directly from structural necessity, it will be sufficient to accept the dimensions which are scientifically correct. The window in Fig. 21 is contained in a steel-framed building, the opening being formed by stanchions at each side and with a light girder over; its proportions would not be acceptable if associated with classical detail, but in many types of modern building is quite appropriate.

Arched Openings. The arch has one drawback: it is not, in itself, in equilibrium, but exerts a thrust which must be resisted to prevent the collapse of the arch. This may be effected by means of a pier, or may result from the balancing of one arch against another in an arcade, in which case the end bay only will require lateral support. Fig. 15 illustrates the arrangement of the end bay of an arcaded façade.

Although good proportions and an appearance of stability are the chief considerations in ordinary cases, and usually ensure safety, the strength of arches in important or unusual positions should be calculated.

The arch has been used in many forms—semicircular, segmental, semi-elliptical, pointed, and horseshoe, each of them sometimes stilted.

In all cases there are three essential constructional elements: *voussoirs*, *keystone*, and *imposts*. These should generally be used as the basis for decoration. An exception is the decoration of the spandril, when a semicircular headed opening is enclosed in a rectangle, but here the ornament will serve to emphasize the strength of the bold, simple arch.

Some of the earliest examples of the arch show the use of a simple mould around the extrados or outer edge of the voussoirs; this was probably the origin of the moulded archivolt, or arch-ring.

The keystone may be emphasized by ornament, and the impost marked by a simple moulding, although there are several beautiful examples in which the springing of the arch is not marked, but the archivolt carried right down to the plinth. See Fig. 22, and also the work of Brunelleschi at Florence.

Arches should, if seen from below, be slightly stilted to allow for distortion in perspective.

The decoration of arched openings by a surrounding order, and the setting of a rectangular opening in an arched recess, provide rich and beautiful compositions (see Figs. 22 and 23).

The arch without mouldings but with strongly marked joints gives an appearance of strength; richness may be added by a decorated keystone.

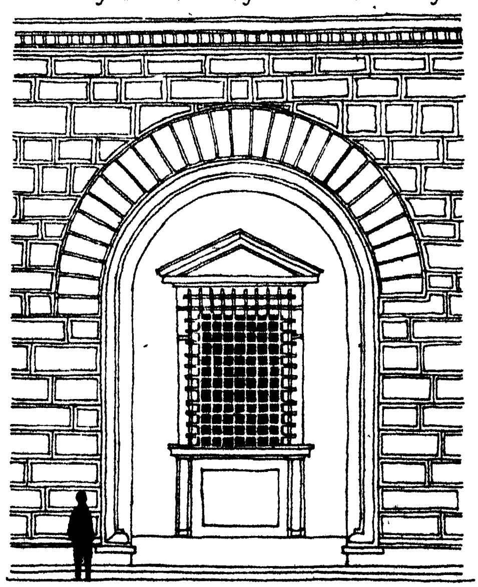


FIG. 22. WINDOW FROM PALAZZO RICCARDI, FLORENCE

The channels or chamfers to the joints should be parallel, the surfaces proper only being wedge shaped.

It has been pointed out that the use of the arch permits wide spans; in many buildings openings are so large that they can hardly be classed as windows, although exigencies of climate may require them to be glazed. Such openings may be required for purposes of lighting large open halls or spaces, such as railway

stations or churches, or may be the expression of scale, combining many ranges of windows in commercial or other buildings. There are many fine examples in the Roman baths and basilicas, and, more recently, the Gare du Nord in Paris, and railway station at Helsinki (see Fig. 24).

They cannot be filled with a single piece of joinery, but must have stone or metal sub-divisions, which will be important elements in the design. Special consideration will have to be given to means of opening for ventilation, and to accessibility for cleaning.

In the architecture of the French Renaissance there are many examples of the linking up of windows in a vertical direction: by pilasters, as at Chambourd, by "chaines" at Balleroy and elsewhere, and in later work by the use of an architrave. This resulted in the first place from the national tendencies towards vertical emphasis; but in the design of modern buildings which are many floors in height, the use of "combined" windows is a valuable expedient, both for the creation of suitable scale and in the relief from monotony which may occur with constantly repeated windows of similar size and shape. Two of the many types are illustrated in Figs. 25 and 26.

There are many examples of combined shapes in window openings, such as the one at Wilton by Inigo Jones, while the possibilities of a continuous range of similar openings will introduce the *portico*, which will be dealt with in the next chapter.

Besides decoration, there are other considerations in the design of door and window openings.

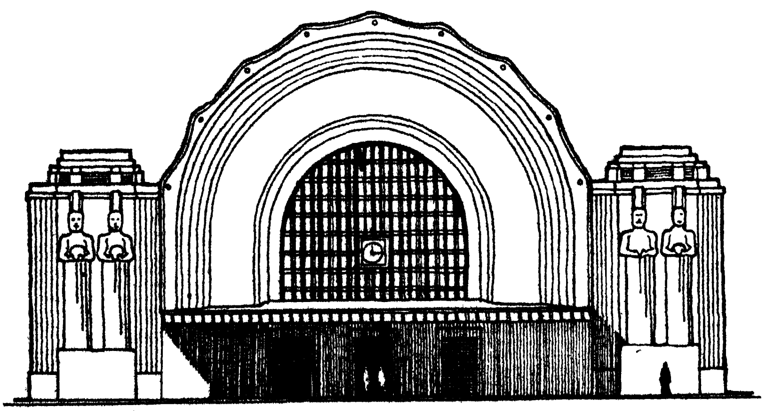


Fig. 24. The Station Entrance, Helsinki

If doors are approached by means of steps, they should have a landing immediately outside. Double doors will be natural at important

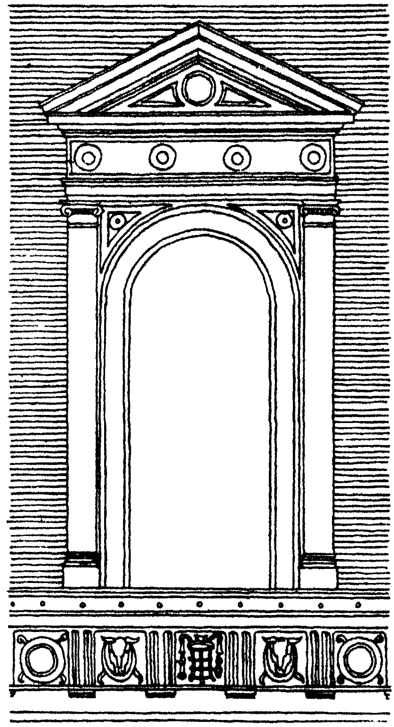


Fig. 23. Window from Palazzo Albergati, Bologna

approaches, and are useful in other positions for the moving of furniture. Door openings, with curved heads, will lead to difficulties in the hanging of doors, because the door will "bind" in the reveal. This may be overcome by raising the arch, as was common in Gothic work, or by inserting a fanlight in the upper part, and making the actual door square-headed. This latter method, however, requires additional height to the opening, and is one of the many reasons for the general use of rectangular door openings in ordinary work.

Window openings are generally similar to doors, but the additional element, the *sill*, is of importance. It should be a single stone, loosely

inserted and fixed when the building has settled, and must have a drip. The height of the sill is of importance in general work, and should not be less than 2 ft. 9 in. above the floor in upper stories. The use of the long, low casement

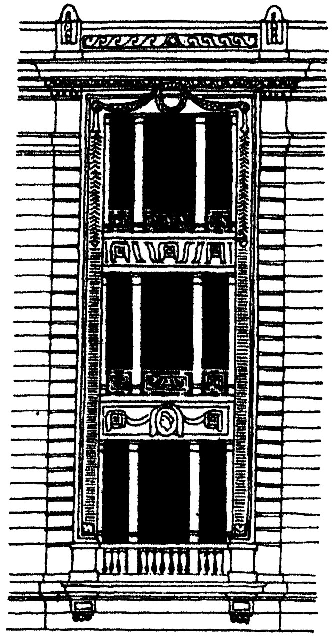


FIG. 25. "COMBINED" WINDOW, PLACE VICTOR HUGO, PARIS

window, in domestic work, will sometimes call for a high sill level in order to secure good appearance, but it should never be so high that a seated person cannot see out of the window.

In a thick wall the portion under the sill, known as the *apron*, is sometimes made thinner and the jambs may be splayed internally to admit the maximum amount of light. The filling of window openings with frames and sash bars for glazing provides fine opportunities for design. There are two general types of opening window—the sliding sash and the casement. The use of either will be determined by questions of utility and stylistic effect.

In modern reinforced concrete work, particularly in the case of continental domestic buildings, the angle window has been introduced with some success (Fig. 27). It will be found that this window normally provides direct light to every corner of a room; this is the only real justification for its use, for construction is difficult and only logical when cantilever construction is employed.

Proportion. The proportions of door and window openings are determined primarily by considerations of use.

Door openings must be wide enough and high enough for human beings; there may be single or double doors according to material requirements; the heights should normally be the same. Proportions determined for effect in monumental

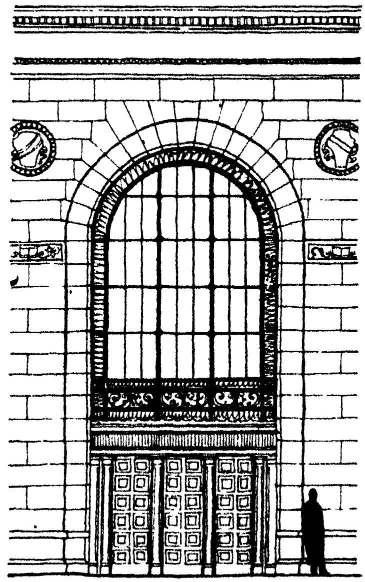


FIG. 26. AN INTERNAL OPENING, THE LIBRARY, DETROIT

work usually give great height, historic examples ranging from two to two-and-a-half times the width. But these openings will usually have a fanlight or other feature in the upper part, as in Fig. 20, or the large doors may be normally open, with a smaller door for constant use inside a lobby.

Window openings are also subject to material considerations—the respective widths possible with casements or sliding sashes, or the need for one or more lights or divisions. In small openings, the same proportions as those of doors are frequently used, though it is logical to make the heights relative to the heights of the different stories, the widths being approximately the same. The proportions of window openings may be adjusted by the introduction of a railing or balustrade, which may or may not be included in the apparent total height by the adjustment of details. In Fig. 25 it will be seen that the railings to the upper windows are too light to affect seriously the proportions of the entire openings, but in the lowest window the opening

appears to end at the top of the more substantial stone balustrade.

Although the use of steel permits lintels to be used over wide spans, it is aesthetically logical that the arch should be employed for the wider openings in a composition, in which classical elements are used; it is also logical that the height to the springing of arches should decrease as the span and consequent thrust increases, thereby increasing the stability. There are, however, notable exceptions in monumental work, in which the opening is about twice its width in height. The Arc de Triomphe in Paris is an excellent example, but here the opening is in scale with every other element in the composition, and its great width is not so apparent.

SIZES OF DOORS AND WINDOWS. Apart from the considerations already enumerated, the size and shape of door openings is capable of variation, except that in buildings used for public entertainment, the dimensions are controlled by local authorities, the minimum widths usually being 3 ft. 6 in. for single and 5 ft. for double doors. In most cases the size and shape of windows should be determined by practical requirements: a minimum area of windows in habitable rooms is usually prescribed by building regulations.

Balconies

The balcony is an accessory which may add great interest to a window opening. Balconies may be limited to one window or be common to several.

When constructed of iron, there is great scope in their design; but when in stone, their treatment is more limited.

The usual elements are round or square balusters with a capping, and a base or plinth. When the balustrade is too long for a single capping stone, it requires solid blocks or dies at intervals, and if continuous over several bays, should have further strength added by means of pedestals. The whole may be supported by a thickening of the wall, as in Fig. 15, or by consoles, or brackets. Ornaments, such as vases, may be placed on the pedestals, though these latter sometimes support columns, as in Fig. 15. The daylight between the dies should equal the width of the window opening—it may be a little wider, but must never be less. Balustrades must always be designed to the human scale; they should be about one metre high. Work of the Italian Renaissance contains many examples of other types of balcony, such as those with stone panels instead of balusters, while the study of the wrought-iron balconies in French work will be very profitable.

The Orders

The best known element in architecture is the Order. The name is used to describe the system of column construction evolved by the Greeks

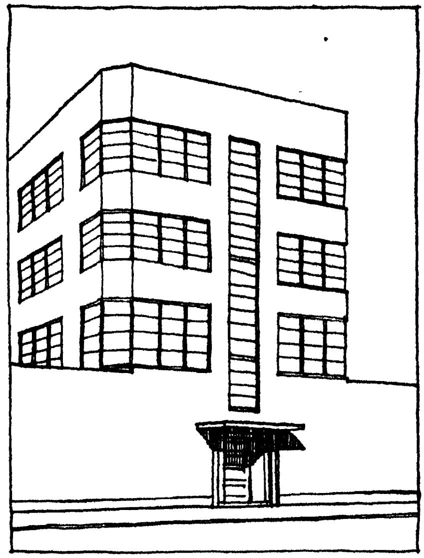


FIG. 27. THE USE OF ANGLE WINDOWS

and subsequently used both structurally and decoratively by the Romans, and almost continuously since the Renaissance. Space will not permit of more than a brief survey of the development of the Orders, but students should make them the subject of special study. The careful drawing out of well-known examples will familiarize the student with details, but study must also take account of scale and proportion. The grandeur of the Classical Orders resulted to a great extent from their fine scale, and historical examples should always be studied with close reference to their actual dimensions.

It will be well, before considering the various subdivisions of the Orders, to consider the principles which underlie their conception, and consequently affect their use in design. The Order was perfected in Greek work, the study of which shows that columns were arranged at regular distances, determined by the maximum span of the lintel; they were circular on plan. The column was not part of a cylinder,

but tapered, being slightly larger at the bottom than at the top, and curved in outline. This shape was logical, for the lower part was more heavily loaded than the upper, and the curved line, or *entasis*, corrected an optical illusion.

The use of an intervening "cushion," or cap, between column and lintel may have been evolved from the supposed wood origin of the Doric Order, but its aesthetic value as a transition from the circle to the square abutment for the lintel is a strong reason for its retention in stone construction.

The lintel, known as the *architrave*, supported two other elements—the *frieze* and *cornice*. These together constituted the *entablature*.

The *frieze*, the middle member, was found in most examples of the Order, and in early examples it probably served to cover the ends of beams carrying the ceiling or roof.

Above the frieze is the *cornice*, a horizontal projection which protected the lower part, and formed the crowning feature of the Order. The upper member of the cornice, the *cymatium*, belonged primarily to the roof; it appears on early examples as a gutter.

The great subdivisions of the Orders were the Doric, Ionic, and the Corinthian. These are dealt with in detail and illustrated in "History of Architecture."

Doric. This Order belongs particularly to Greek architecture. The extent to which it owes its form to a wooden prototype is debatable; its development in stone shows little variety in detail, progress being always in the direction of the perfection of proportion of an accepted simple form. The frieze is the distinctive feature of the Order, and the spacing of its metopes and triglyphs is closely related to the spacing of columns. In Greek temples there is a triglyph at the end of the frieze, thus causing the end columns to be more closely spaced than the rest. This results in actual and apparent stability, and still leaves the wider passage in the centre where it is required.

In many early Roman examples of this Order, Greek detail was followed closely, but later it lost its character of refinement and majesty. It acquired a base, a moulded abacus, and other ornamental features. The column became more slender and the entablature less deep, but the triglyph was still an important controlling element in the design.

Ionic. If the Doric Order may be called "masculine," then the Ionic is distinctly "feminine" in its grace and elegance. The characteristic feature was the voluted capital, which was usually rather plain. In Greek work, the volutes were parallel to the entablature, an arrangement which produced a fine capital, but presented serious difficulty at the angles of a building where a column is related to two elevations. Antae, or pilasters, were sometimes used at the angles to obviate this difficulty. Bases were generally moulded, and in some cases the base of the column was sculptured, as at the Temple of Diana at Ephesus. The Romans often used the horned or diagonal volute.

The entablature was composed of the three elements found in the Doric Order. The architrave was usually subdivided into three faces; the frieze was plain or enriched with sculpture in relief; the cornice was extremely simple, although in some cases a dentil course added a certain amount of interest and richness.

Many of the mouldings were enriched with the egg-and-tongue or other carved ornament, in some cases skilfully adjusted in detail to suit the light falling on it.

Corinthian was essentially a Roman Order, for its rich decorative character appealed to the emperors, and was in accordance with the social ideals of the Roman epoch. There are few examples in Greek work, the best occurring in smaller buildings and monuments, such as the Tower of Winds and the Choragic Monument of Lysicrates. Although the original structural lines of the Doric Order were retained, the Corinthian Order was used chiefly as a decorative feature. The earliest Roman examples were robust, later becoming more slender. The shaft of the column was frequently of coloured marble, and in consequence flutes were logically omitted. Bases and capitals were highly decorated, the treatment of the latter being carried to excess in some later examples. The entablature reflected the richness of the capital; the architrave is usually simple, as is the frieze, although this is sometimes decorated as in the Temple of Vesta, at Tivoli. It was in the cornice that the Romans excelled. The voluted modillion and the enrichment of the mouldings with acanthus leaf motifs are the characteristic features amongst the extraordinary variety of detail used.

Composite is a variety of the Corinthian, the only important variation being the use of a larger volute in the capital.

The Roman Orders were frequently placed on a pedestal, which was from 2½ to 3½ times the diameter of the column in height. The

pedestal, however, is more usually associated with the balustrade, and should, therefore, conform to the human scale, having a constant height of about 3 ft. or 3 ft. 3 in. By this means it will give the true scale to the column superimposed, instead of producing the appearance of a magnified "Order."

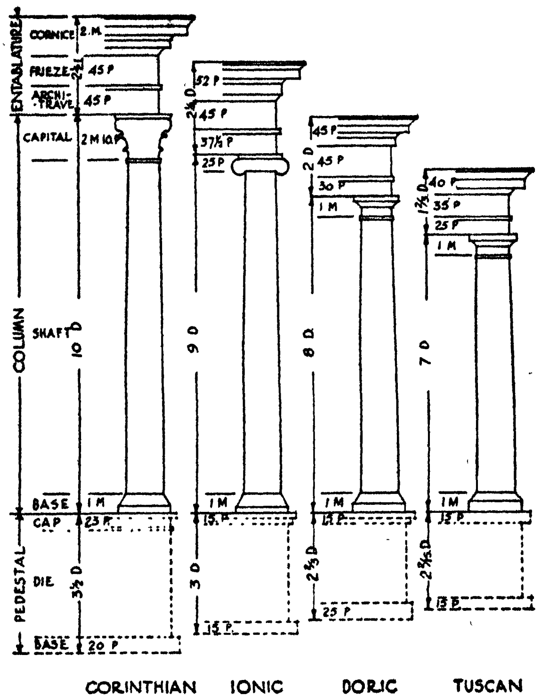


FIG. 28. THE PROPORTIONS OF THE ORDERS, ACCORDING TO VIGNOLA

Units of Measurement · D = *Diameter of Column*; M = *Module, or* ½ D; P = *Parts*: 30 *parts* = 1/*M*

Proportions. Before considering the use of the Orders in buildings of more than one story, it will be well to consider the proportions which resulted from their use on the monumental work of the Greeks and Romans. The relative sizes of columns and entablature are, perhaps, the most important distinctions between the various styles. There are several systems of standardization of the Orders, using the diameter or half-diameter of the column as the unit of measurement. These are useful for general guidance, but the ancients were not bound by any hard and fast rules of proportion, as the infinite variety of their work shows. The proportions of the various parts of the Orders are given in Fig. 28, but the student is advised to study in detail the various published drawings of the Greek and Roman Orders.

In the spacing of columns other than in the Doric Order, there are no special requirements as to the exact arrangement, although where the cornice contains modillions, these should be spaced so that a modillion is on the axis of the columns. Fig. 29 shows a few of the spacings and the terms used to describe them.

The study of Greek and Roman temples will show the variety of ways in which the Orders may be used. Some typical arrangements and their nomenclature are given in Fig. 30.

Special attention should be paid to the use of the *anta*. When columns are placed in front of a wall, and the entablature returns to the wall, an *anta* should be introduced. to support it; see Fig. 30 (*A*), (*B*), and (*C*).

An interesting break from the proportions usually associated with the Orders is to be seen in the "Colonial" style of America, which was adapted from English Georgian architecture. The buildings were generally constructed of timber, and as was natural, the material greatly influenced the proportions of the Orders used. Columns, formed from a single piece of timber, were very slender, being as much as eighteen or more diameters in height; the entablature was proportionate to the diameter rather than the height of the column, while the spacing was normal to the height of the column rather than the diameter.

SCALE. After the first general proportion is settled, the question of scale must be considered.

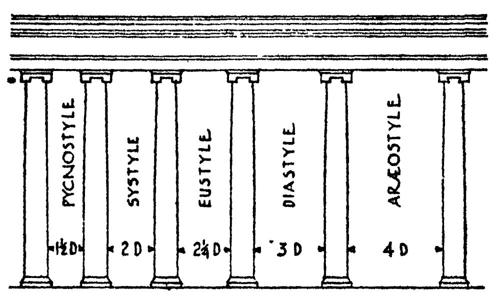


FIG. 29. THE SPACING OF COLUMNS

It is obvious that small and large Orders should not have the same detail, while the position of the Order must always influence its scale and proportion.

Spacing. In the portico, the number of columns would appear to influence the spacing of the columns. One opening between two

columns must be wide enough to give ample passage, while a number of openings between four, six, or eight columns gives an increasing choice of passage, and the spacing may therefore be decreased. Tradition seems to confirm what logic dictates.

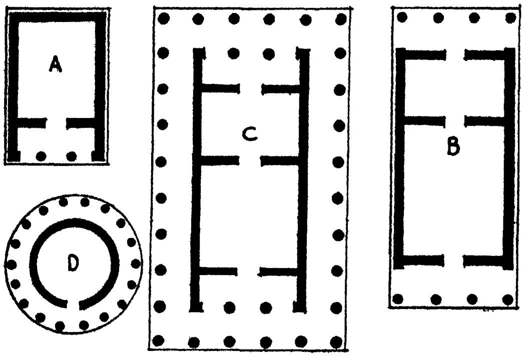


FIG. 30. SOME TYPICAL ARRANGEMENTS OF COLUMNS

A = *Distyle in antis*, two columns between antae
B = *Amphi prostyle tetrastyle*, four columns in front at each end
C = *Peripteral hexastyle*, columns all round with six at each end
D = *Circular peripteral*

NOTE. A range or portico of eight columns is known as *octastyle*, or with ten, *decastyle*

Sometimes Orders of two sizes may be used in the same building, as in Fig. 31. Here, the safe span of the lintel permits equal distance between the centres of both series of columns, but the proportionate spacing is narrower in the case of the taller Order. It appears logical, therefore, that the taller the Order, the closer the relative spacing of the columns, but this usually resolves itself into a question of taste.

Superimposition of Orders. The requirements of Roman and later civilizations called into existence buildings of more than one story, and it was inevitable that their decoration should involve the use of the Orders.

In Roman and Renaissance buildings in Italy, the most frequent arrangement is the use of an Order to each story, with arched openings between the columns, a treatment permitting great variety and interest.

The superimposition of Orders is not merely the placing of one Order upon another. The stories must be welded together, and the composition unified by means of a cornice which is not only an element in the upper Order, but must dominate the whole façade. This may result from the sequence in which the Orders should be used, viz. starting from the ground, there will be Tuscan, Doric, Ionic, Corinthian, and Composite. This sequence must always be used, although it is not necessary to commence with any special Order. It will be seen that not only will the topmost cornice be the richest, but that there will be a decrease in "weight," or sturdiness, towards the top, which is logical, both aesthetically and structurally (see Fig. 32, and also the Colosseum, Rome).

The balustrade and the fine deep frieze, in Fig. 32, are interesting methods of providing emphasis at the top of a building sufficiently important to unify the composition.

Frequently the entablature is broken around the columns, or pilasters, on either the lower story, or both, as in the Banqueting Hall, Whitehall. This treatment will give a vertical emphasis which prevents lack of cohesion in a composition consisting of two equal parts.

The spacing of columns will require adjustment in superimposed Orders. In Fig. 33 each story seen separately is satisfactory, but together, the closeness of the columns is very depressing. It will be appreciated from this illustration that the eye is inclined to "read" the total height of the building against the distance apart of the columns, and that the spacing should, therefore, be wider than is customary in porticoes.

There are many examples in which the Orders

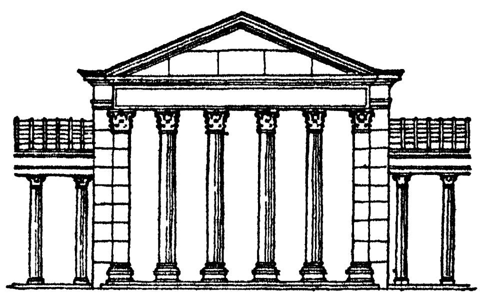


FIG. 31. PORTICO OF OCTAVIUS, ROME

are used for upper stories, standing upon a wall or arcade (see Fig. 34). Here, again, the spacing must be adjusted to take account of the greater height of the building. It will be seen that in Fig. 34 the Orders are used to embrace two stories.

Bays with coupled columns will require wider spacing than those with single columns, not merely to find room for the extra column, but in order to clearly distinguish between the space between the pairs of columns and that between the coupled columns. In the latter case, spacing

is regulated by the projection of the bases and capitals.

There is infinite variety in the handling of classic features in the work of the Italian Renais-

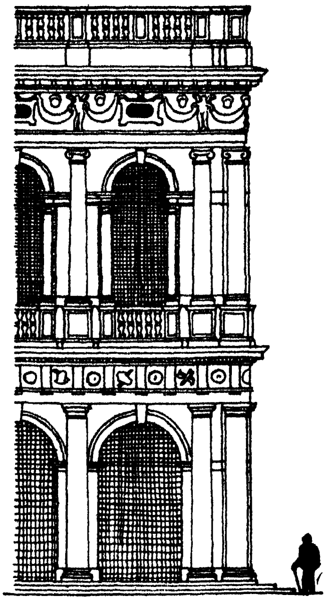


FIG. 32. LIBRARY OF ST. MARK'S, VENICE

sance, one of the most interesting being the "Palladian" motive in Fig. 32, and developed more fully in Palladios Basilica, at Vicenza;

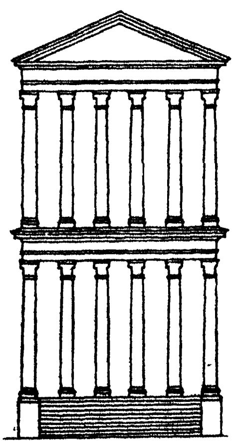


FIG. 33

another version of which may be seen in the open loggia of the Villa Medici (Fig. 35).

Arcades. The simplest form of arcade consists of a series of arches supported on rectangular piers. The piers themselves may be plain or panelled, with an impost mould and a moulded archivolt, or the whole may have channelled joints as in Fig. 34.

The use of the round column as the support between the arches provides the most graceful form of arcade, but its construction requires considerable care.

One of the finest examples is that illustrated in Fig. 36, a close examination of which shows that: (1) The caps and bases are of marble, and the shaft of the column monolithic and of granite. This has constructional significance, for not only is a hard, dense stone necessary to

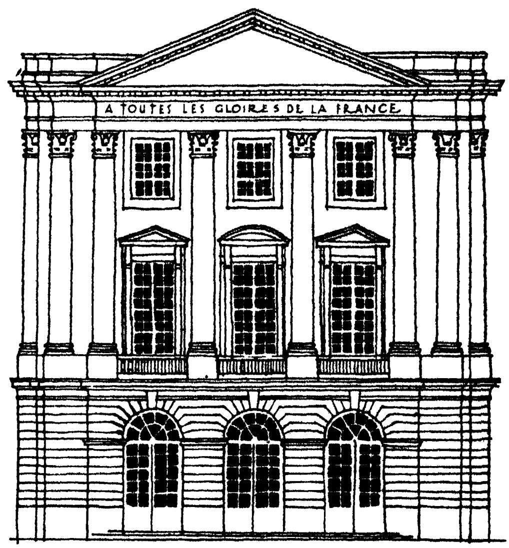


FIG. 34. PAVILION GABRIEL, VERSAILLES

carry the load concentrated upon so small an area, but the liability of lateral displacement of small stones leads to the use of a monolith. (2) The vault between the arcade and the wall behind is tied back to the main wall with iron ties. The reason for this precaution is obvious.

The entablature is usually omitted from the columns supporting these arcades, for it would have no structural significance. There are, however, examples where a modified form of entablature has been used, particularly in Brunelleschi's work in Florence; the study of the interior of the Church of San Lorenzo will make his reasons clear.

Arcades may be decorated by means of circular panels, or openings, in the spandrels,

or by means of carved enrichment, which conforms generally to the shape of the spandrel. Study of the work of the Renaissance in Italy will reveal many examples.

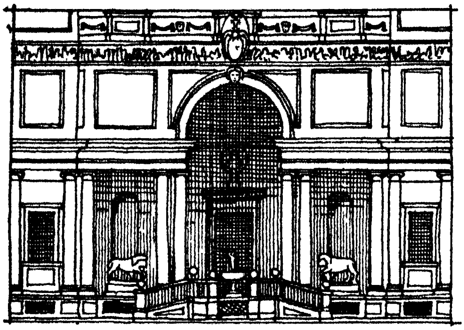


FIG. 35. THE OPEN LOGGIA, VILLA MEDICI, ROME

The delicate nature of the single-column arcade tends to limit its height, and the need for better support leads to the use of coupled columns, when an entablature becomes necessary to tie the columns together; see Fig. 37.

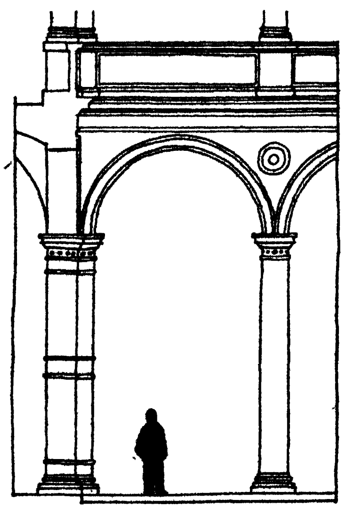


FIG. 36. THE LOWER ARCADE, PALAZZO CANCELLARIA, ROME

The ground story in Fig. 38 shows an Order used to provide extra strength to the support. The upper part is very interesting; the slender intermediate column which is introduced to support the upper entablature is, perhaps, a breach of structural laws, but its value in reducing the scale of the opening and giving two well proportioned shapes cannot be exaggerated.

It has been pointed out that the arch, in itself, is not in equilibrium, and that the end bay in an arcade will require a buttress to resist the oblique thrust from the arch. When the end pier was the same as the intermediate piers, a tie-rod was essential to the stability of the structure. Although many authorities have accepted this method, its adoption at once suggests possibility of failure, and therefore destroys the feeling of repose. It is therefore preferable to provide a buttress, or substantial angle, which

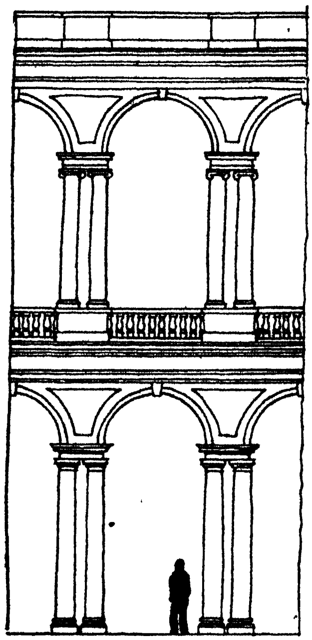


FIG. 37. THE COURTYARD, PALAZZO BORGHESE, ROME

has a definite place in the composition; see Fig. 32. This not only has apparent and real structural value, but it punctuates the façade in an excellent manner, creating a feeling of completeness.

Where an entablature is introduced above an arcade, the architrave should usually be omitted unless there are columns, pilasters, or keystones to support it; compare Figs. 36, 37, and 38.

When the Orders and arches are used in combination, it is advisable to give emphasis to one or the other: to the arches, by means of as great a depth of reveal as the scheme permits; or to the Order, by advancing it from the face of the wall, and exposing a bold soffit to the entablature, which should contrast with a shallow arch.

The proportions of arches used in arcades are

usually based on those found in traditional architecture, a height of twice the diameter being productive of the best results.

It is not possible here to consider arcades in medieval architecture, which, although they conform to similar laws, are subject to very different spiritual and material considerations in their composition.

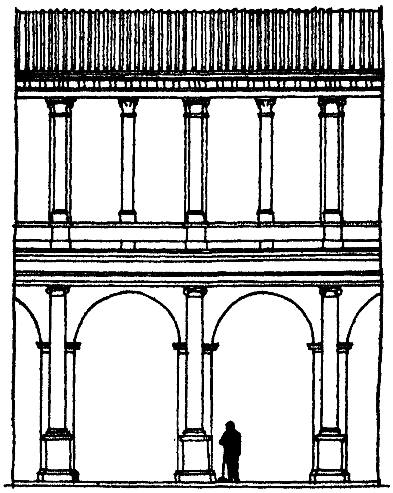


FIG. 38. THE CLOISTERS, S. MARIA DELLA PACE, ROME

ROOFS

The simplest building will require a roof.

The object of the covering is to protect the building from the weather; its actual form is determined primarily by the method of its construction, and this in turn is closely related to the size and shape of the space covered.

Form. In all designs the form of roof must be considered from the commencement, primarily as an essential part of the "structure," but also as an element which may possibly be expressed in the external treatment. Its form may be determined by the method of spanning the enclosed spaces, or it may be desired for effect only.

In antique architecture of Greek and Roman origin, the roof rarely exists except as a protective covering, frequently used over a vault or other ceiling. In medieval buildings in Europe, the exigencies of the climate required a steep roof, which became a feature of importance. The Renaissance architecture of France contains many fine examples of elaborate roof treatment, and is perhaps the best period for study.

In domestic work in Europe, the relative cheapness of tiles and slates, and their efficiency as a protection against wet weather, are the factors influencing their use; consequently, the pitched roof is an essential feature in buildings of this kind. In modern practice, the roof rarely becomes an architectural feature owing to the use of concrete and asphalt, but a type of mansard is sometimes employed, both when a maximum of accommodation is required and for purposes of design.

In most districts, the provision of stories in a roof, in excess of the maximum height of building, is permitted.

The factors to be considered in roof design are the method of spanning the space, the material to be employed, and the slope at which it must be laid for efficiency in the disposal of rain-water.

Roofs may have *flat* or *curved* surfaces. The former, when suitable for the material employed, are logical, but curved surfaces are in most

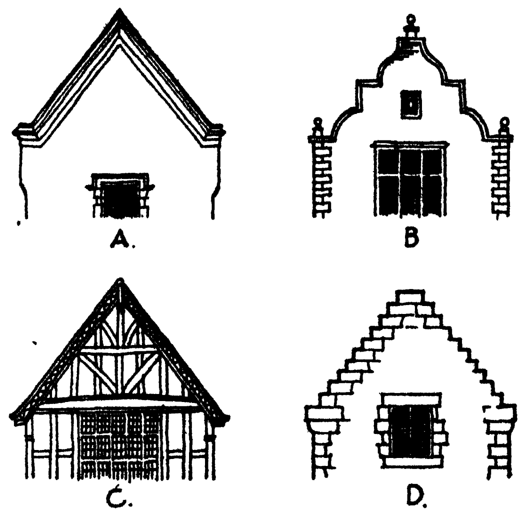


FIG. 39. GABLES

A = A brick Tudor gable
B = Early Renaissance
C = Half-timber
D = "Corbie," or crow steps, found in Scottish and Flemish work

cases merely decorative and open to criticism, because of the flatness of the upper part.

Construction. In general, roofs should be simple in shape, and of consistent slope throughout a design. In a pitched roof, the ridge will normally be parallel to the longer direction of the room or building, the ends being either hipped or terminated against a wall. If the

slope is not steep the gable end may form a pediment, characteristic of classic architecture; in other cases a gable, of which there are many interesting varieties to be found, particularly

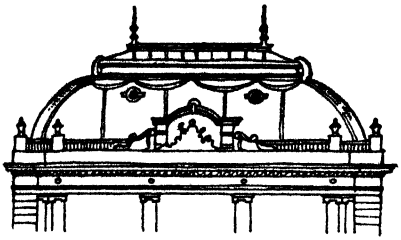


FIG. 40. ROOF OVER END PAVILION, LE PETIT PALAIS, PARIS

in the early Renaissance work in Western Europe (Fig. 39), will be required.

Roofs with curved surfaces are usually hipped. They were used in great variety in the later Renaissance in France, and still find favour in that country. They are usually exceedingly rich and ornamental, the flat part at the apex

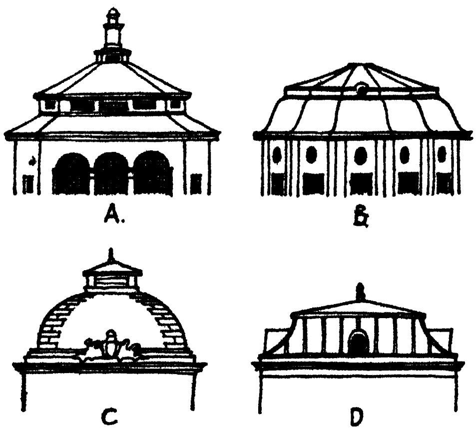


FIG. 41. TYPES OF ROOF

A = 5th Avenue Hospital, New York
B = Theatre, Bremerhaven
C = Palais de Justice, Paris
D = Pavilion, Worthing

and the hips usually being covered with lead or zinc, and highly decorated with crestings and finials; see Fig. 40.

Roofs over square or polygonal plan forms are sometimes referred to as domes, but their construction does not usually justify this description. They are met with in Renaissance and modern architecture in great variety, giving interest to the silhouette of otherwise simple buildings (Fig. 41).

The roof with broken surfaces, or two slopes, is known as the *mansard*; this also is essentially a French feature, and is usually richly treated in a similar manner (see Fig. 42). The mansard may consist of four distinct surfaces, or the upper part may be flat.

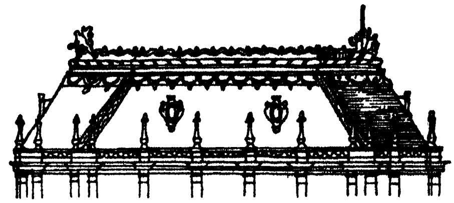


FIG. 42. ROOF OVER THE CHAPEL, VERSAILLES

Dormers. Although the steep roof had a functional origin, its contemporary use is chiefly for effect. It was natural that the space in the roof should be used, and the need for lighting produced the dormer. Dormer windows may rise from the face of the wall, as in Fig. 43 (*C*) and (*D*), but this leads to difficulties with the gutter, which ought, for economy, to be carried

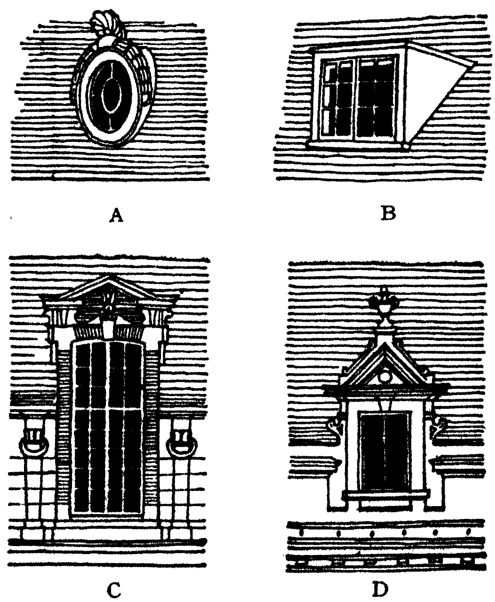


FIG. 43. DORMER WINDOWS

right round the building without frequent breaks.

The steep roofs of the French Renaissance contain many fine varieties of the dormer as a disconnected feature.

In domestic work the dormer may be a necessity, but its construction requires great attention owing to the intricate roof work involved. Careful study will show that the

materials used in roofs will greatly influence the form of dormers which are formed in them. Fig. 43 (*A*) and (*B*) illustrate two simple types.

Chimney Stacks are of great importance to the roof. They must be anticipated in the plan, so that they project at the best position, both for the construction of the roof and for the composition of the masses.

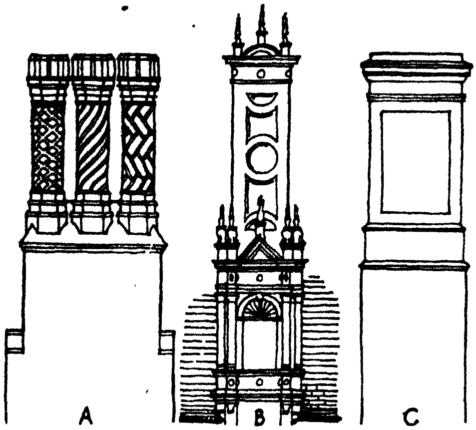


FIG. 44. CHIMNEY STACKS
A = Hampton Court
B = Chateau de Chambord
C = A —odern type

Structurally they are simplest at the ridge, difficult through a hip or the eaves, and quite impracticable through a valley.

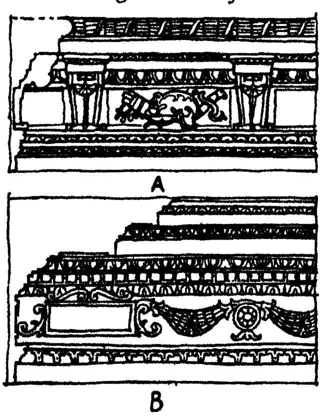


FIG. 45. INTERIOR CORNICES
A = Salon de la Guerre, Versailles
B = A modern example

In formal design, chimneys should be arranged symmetrically if the plan permits; in any building a few large stacks will look better than a large number of small ones scattered about. The top of the chimney should rise above the roof, and since it is a conspicuous feature, the cap should be treated carefully. Fig. 44 illustrates a few characteristic types.

CEILINGS AND FLOORS

The ceiling is usually developed as the underside of the roof or floor construction, although in special circumstances it may be separately formed as a false ceiling, as in the theatre (Fig. 3).

Floors and roofs constructed with beams will usually produce a flat ceiling, while some types of truss-construction may produce curved ceilings, which are frequently decorated in imitation of the underside of a vault. The vault is naturally produced by the application of the principles of the arch to roof construction.

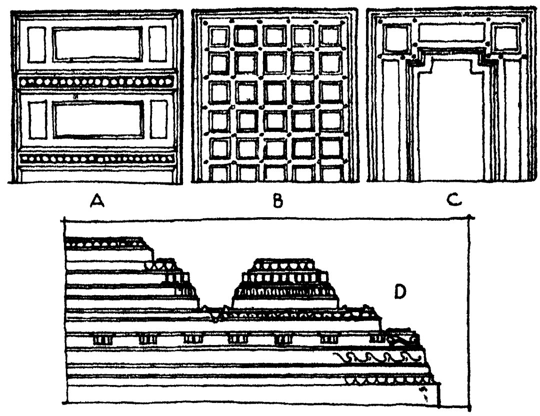


FIG. 46. TYPES OF FLAT CEILINGS

FLAT CEILINGS. The consideration of flat ceilings at once involves the study of upper floors.

It will be obvious that in the enclosing of any required area with walls, the problem of the construction of the floor over will be simpler if the shape is oblong rather than square, for it will be logical to place joists, or girders, across the shorter span.

The fundamentals of floor construction are beams, or joists, with a covering of boards in the case of timber construction, or a concrete panel, or bay, in modern fire-resisting construction. Without discussing the various methods of construction of floors, they may be classified as floors with all joists of the same depth, and floors with beams, or girders, as well as joists, and under these two headings we may consider the decoration of ceilings.

In the first case, they are usually plastered, although in medieval work the joists were frequently left exposed, a practice still carried out for special effects in domestic work.

Plaster ceilings may be plain or enriched

with ornament in relief. It is profitable to study the rich ceilings of the Renaissance, the more restrained but still heavily ornamented ones of the seventeenth and early eighteenth centuries, and the refined and delicate work of the Adam period.

The *cornice* at the top of the wall is the most common type of enrichment. It may be a simple run plaster or wood mould, or may consist of an elaborate entablature ; see Fig. 45 (*A*) and (*B*).

Ceilings with beams may be treated in bays (Fig. 46 (*A*)), or may be subdivided into coffers (Fig. 46 (*B*)). There are many beautiful examples of coffered ceilings in which the " beams " do not represent a logical construction (Fig. 46 (*C*)). The wall cornice usually

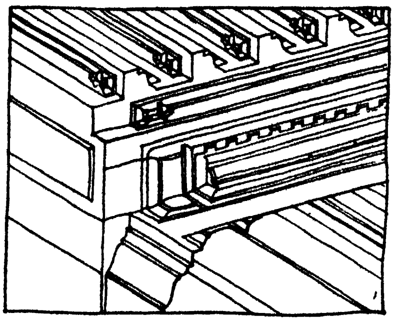


FIG. 47. CEILING AT THE HOTEL DE VILLE, BEAUGENCY

provides the basis for decoration, the upper members being run around each compartment (see Fig. 46 (*D*)). The beds of the coffers, or bays, may be decorated with ornament in relief, or with paintings.

Framed floors in timber are rarely used nowadays, but may sometimes be employed for effect. Fig. 47 illustrates an example worthy of study.

When large spans are necessary, it is now the general practice to use steel or reinforced concrete, but the decoration of the ceiling will be governed by similar considerations.

Considerations of " interior scale," and relatively poor light indoors, will require a sharpness of outline in ornament and mouldings ; these may be accentuated by the use of colour.

VAULTS

The subject of *vaults* is so large that it is impossible to do more than suggest the principles underlying their construction, and to indicate the general types. In architecture there is nothing more noble and beautiful, but no other feature requires more knowledge.

Although the vault is the development of arched construction, it is, in its simplest form

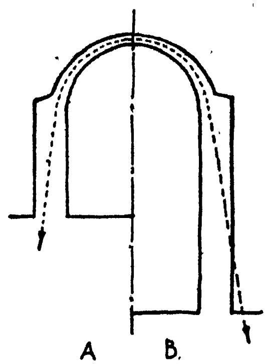


FIG. 48. THE STABILITY OF VAULTS
A = Stability
B = Instability due to increased height

—the *barrel vault*—subject to vitally different considerations. The arch exerts a thrust in the direction of the length of a wall, but the vault presses against the face of the supporting wall.

Without discussing in detail its stability, it is sufficient to point out that the resultant of the

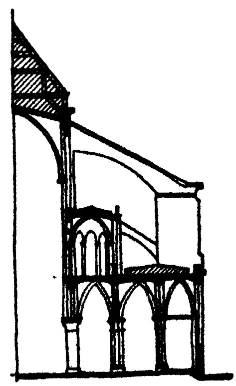


FIG. 49. THE SYSTEM OF VAULTING AND BUTTRESSING AT NOTRE-DAME, PARIS

forces acting in a vault must fall within the section of the wall, usually within the middle third (see Fig. 48).

The thrust of the vault may be resisted by buttresses, or by the use of iron ties ; by a system of arched ribs supporting a light filling, it may be concentrated upon suitably arranged points of support ; or it may be almost entirely obviated by the use of sufficiently thick concrete, which is monolithic when set.

In medieval work, the thrust of the vault is

frequently directed in a safer downward direction by the loading of the abutment by pinnacles, the piers being supported by flying buttresses (see Fig. 49).

The height of the wall will influence the

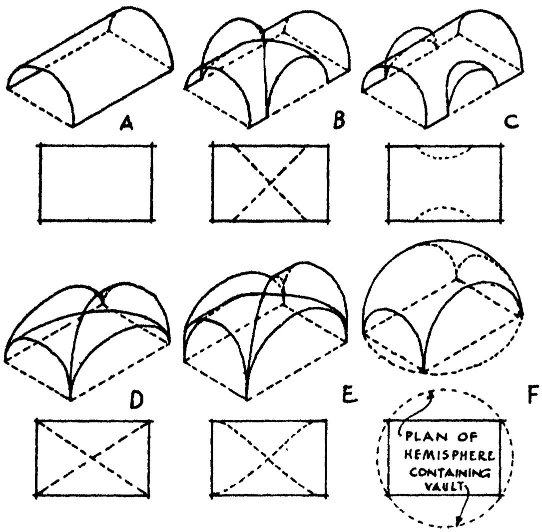


FIG. 50. VAULTS

A = Semicircular barrel vaults
B = Intersection of semicircular vaults of equal span
C = Intersection of semicircular vaults of unequal span
D = Intersection of semicircular and semi-elliptical vaults (groin straight on plan)
E = Intersection of semicircular vaults, the smaller one stilted to produce level ridge (distorted groin on plan)
F = Domical vault over rectangle
(*Dotted lines indicate groins on plan*)

stability of the vault and its support (see Fig. 48), as will the weight of the material. The use of light material for the vault and heavy material for the wall is obviously logical.

Vaults have been constructed in three general systems: cut stone, stone or tile arches or ribs with a light filling, and concrete. The use of steel-framed trusses in modern work may simplify the question of *actual* stability, but the vault must always *appear* stable; this will result from the acceptance of traditional forms as a basis for design.

The vaults of the Romans were frequently built of a tile skeleton with a filling behind, making the coffer decoration a direct outcome of the construction.

In vaults of cut stone this system of decoration is illogical, for the construction implies a gradual thickening of the stone towards the springing. Projecting panels are the natural method of decoration, although coffering is sometimes used on account of its richness. Enrichment should always accentuate construction. The cornice, when used, should have the appearance of supporting the vault.

A most appropriate type of decoration for the vault is painting; among the finest examples are the geometrical paintings in Pompeian work, and the pictorial work of the Renaissance.

Vaults may be divided into two sections: those with a continuous thrust, and those with localized thrusts.

The barrel vault (Fig. 50 (*A*)) is typical of the first section. It is the simplest form of vault, and is primarily suited for rectangular plan forms, or long galleries; it may be used over a square when the semicircular ends, or tympani, admit light, or in lateral bays as elements in a larger composition, such as the Basilica of Constantine. In this latter example it is coffered; but when used over a long room, or gallery, its length may be accentuated by low relief decoration, or relieved by deep arches at intervals.

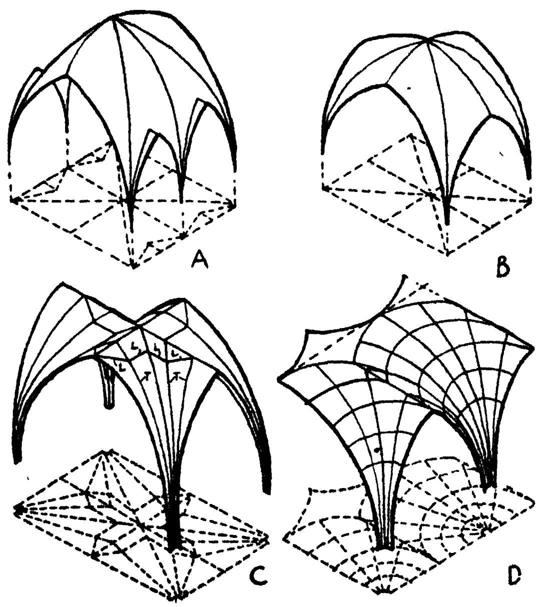


FIG. 51. THE GOTHIC VAULTS

A = The sexpartite vault
B = The quadripartite vault
C = Vault with *Tiercerons* (*T*) and *Lierne* ribs (*L*)
D = The fan vault (half only shown)

Vaults with localized thrusts result usually from the crossing, or intersection, of barrel vaults. They are usually employed over plan forms which are subdivided into bays, but may occur separately, as at the crossing in a church. The simplest form is the intersecting vault

(Fig. 50 (*B*)), the many developments of which may be traced through Romanesque and Gothic architecture in Europe.

A series of diagrams is given in Fig. 50, which illustrate the salient points for consideration in the design of vaults arising out of the use of

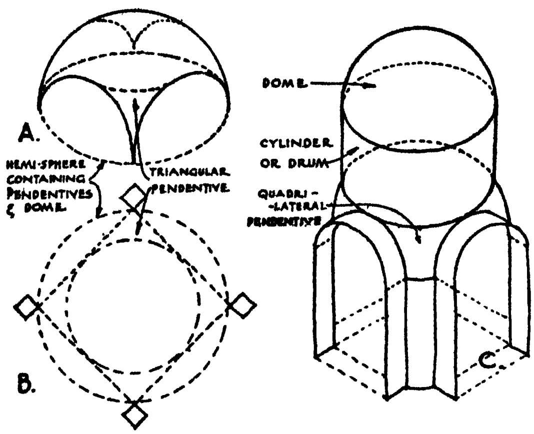


FIG. 52. THE DEVELOPMENT OF THE PENDENTIVE
A & B = The simple dome contained in a Hemisphere, with triangular pendentives
C = The dome raised on a Cylinder or Drum supported by quadrilateral pendentives

circular forms. Vaults which were used in Gothic works were usually based upon the pointed arch, and although subject to similar

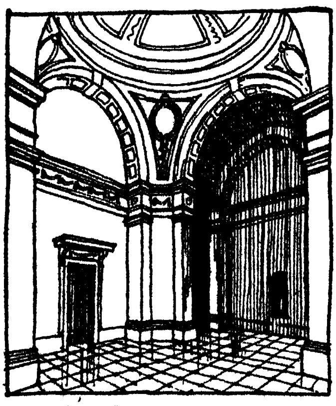


FIG. 53. THE DOME ON QUADRILATERAL PENDENTIVES

considerations they were developed much further. Fig. 51 shows the general types of vault in outline.

The study of vaulting is difficult at all times, but without a thorough knowledge of geometry it is impossible. Actual examples are the best reference, for it is then possible to examine the reason and the result. Vaults must not only look well in elevation and on plan; the shape of the groin is perhaps the most important consideration, and must not be left to take care of itself, but set up carefully in the working out of the design.

DOMES

The earliest dome of importance is that of the Pantheon, Rome. It is the simplest form, consisting of a hemisphere rising from a circular plan. The smaller domes of the Romans were usually lower and saucer-shaped. The greatest factor in the development of the dome was the *pendentive* (see Fig. 52). It enabled the dome to be erected over a square plan and, as with the groined vault, localized the load.

The simplest form is the triangular pendentive as in St. Sophia, Constantinople, but this is open to criticism, as it appears to stand on a point. A splayed angle (Fig. 53) is, therefore, preferable, as it provides a more substantial quadrilateral pendentive, as in the Pantheon and the Invalides, Paris, and at St. Peter's, Rome.

The subsequent heightening of the dome by means of a lantern, or drum, is logical structurally, although it requires most careful handling both for stability and appearance.

Domes may be coffered, or a rib construction may be indicated in the decoration. Both are logical, and permit great variety of treatment.

Although domes were primarily evolved as a means of covering large areas without intermediate supports, their use during and since the Renaissance has also been very largely determined by the desire for external effect. As such, they should properly be considered as a form of roof, but their design must always be closely related to that of the internal domical vault or ceiling.

It is evident that the consideration of effect will involve the use of different profiles internally and externally. In the former case, a semicircular or flatter section is usually required, while in the latter a steeper form is necessary, particularly if the dome is raised on a drum; many of the finest examples are semi-elliptical or slightly pointed.

A high dome immediately calls for an important crowning feature, such as a lantern, the support of which presents great constructional difficulties if it is constructed of a heavier material than that of the structure below. Careful study of the domes of St. Peter's, Rome, St. Paul's, London, and the many domed churches in Paris will show how these

problems have been solved. It must be pointed out that a high domical ceiling over an auditorium will present serious acoustic difficulties, and the desire for effect in such cases must be tempered with an appreciation of the more vital need for usefulness.

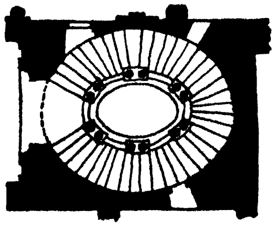


FIG. 54. PLAN OF THE OVAL STAIRCASE, PAL. BARBARINI, ROME

STAIRCASES

The Staircase is an essential element in the planning of buildings of more than one floor. As an element of composition, its type and location will be referred to in a later chapter.

FIG. 55. THE STAIRCASE, CRANBOURNE MANOR HOUSE

INTERNAL STAIRCASES. The earliest form consisted of a number of stone steps in a single straight flight, supported at either end by a wall; many modern staircases of a monumental character follow this principle, and rise from floor to floor in one broad flight. The spiral staircase with a solid newel arose from the need for economy in planning, the staircase in medieval military architecture being an unimportant feature. From the fifteenth century onwards, particularly in Italy and France, stone

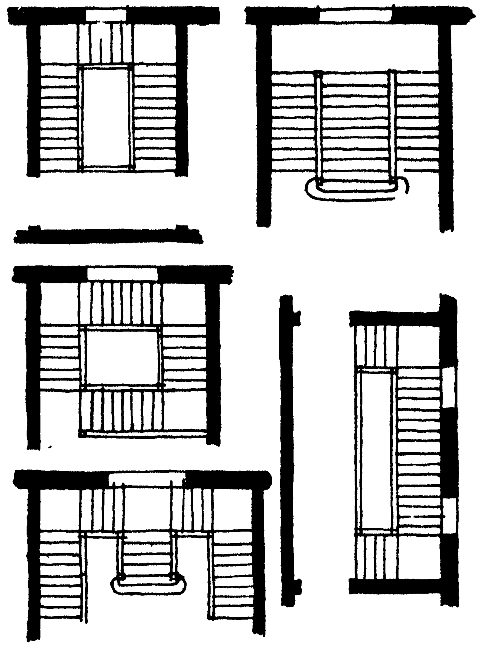


FIG. 56. STAIRCASE PLANS

FIG. 57. THE MAIN STAIRCASE, PETIT TRIANON, VERSAILLES

staircases of various shapes were evolved; Fig. 54 illustrates one interesting type; there are fine examples at Chambord and Blois in France.

The evolution of the staircase hinged upon the gradual hollowing out of the well, and elimination of the wall supporting the outer ends of the

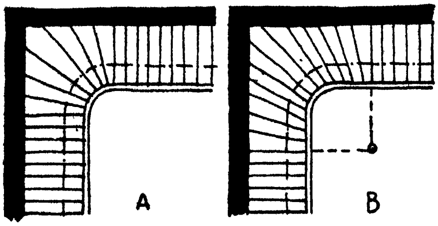


FIG. 58

A = Winders
B = The arrangement of "Balancing," or "Dancing" stairs

steps. The study of the examples referred to will show that a series of columns, around the inner edge of the staircase, took the place of the wall, supporting one side of a vault which also rested on the outer wall, the vault being the soffit of the stairs.

The work of the Renaissance in England shows the development of the staircase in timber. In early work, the staircase consisted of a number of short straight flights, the newel posts being continued from floor to floor as means of support (see Fig 55).

In the seventeenth century, stairs became simpler, and it was the practice to support the outer edge of the staircase by an inclined beam, known as a *string*. The subsequent development of the staircase produced a

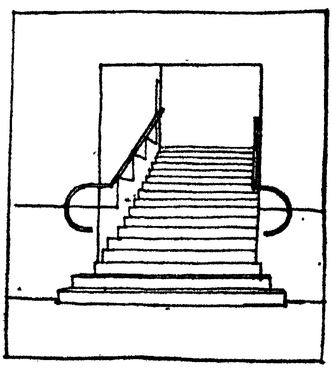


FIG. 60 *A*

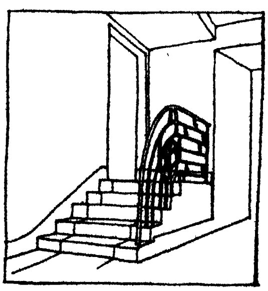


FIG. 60 *B*

great variety of decorative treatments. Typical plans are given in Fig. 56.

Apart from variations in the detail of handrails, balusters, and newel posts, the two types of string—"cut" and "close"—are the most distinctive differences. The best examples of the former are found in the later work of the eighteenth century in England, while the latter has been used continuously in France. The latter country has produced many of the finest monumental staircases; that illustrated in Fig. 57 is characteristic of the best work of the eighteenth century.

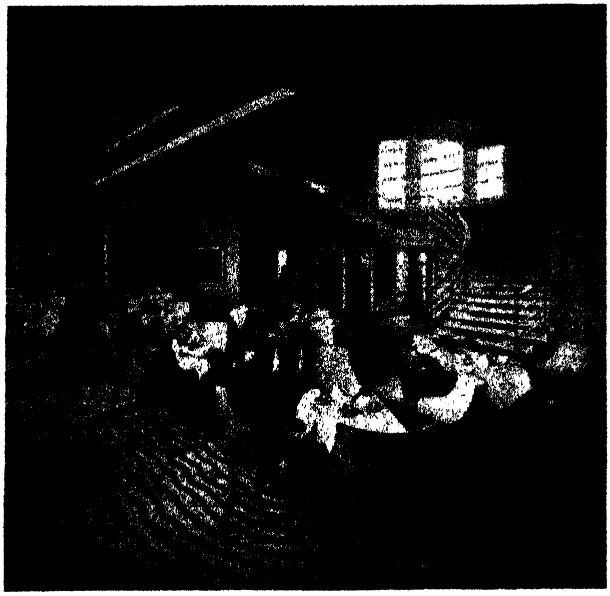


FIG. 59. THE MIDLAND HOTEL, MORECAMBE
The Main Staircase

In the design of a staircase, it must be remembered that simplicity of plan is the keynote of dignity and grandeur of scale.

The proportions and dimensions of tread and riser are the most important considerations, in the determining of which either of two rules may be adopted. In one case, the width of the tread in inches, multiplied by the height of the tread in inches, should equal 63 to 65; in the other, twice the riser, plus the width of the tread, should equal 23 in. Actual dimensions range from 13 in. by 5 in. to 8 in. by 8 in., but the latter is very steep, and should only be used where economy in space is paramount.

When staircases are curved, the dimensions should be measured about 18 in. from the handrail, this being the point at which people usually proceed up or down.

Winders, although sometimes necessary in

close planning, are usually objectionable, and when employed, should be introduced at the bottom of a flight rather than at the top. It is an advantage to use an odd number of winders, and so avoid the awkward recess in the angle.

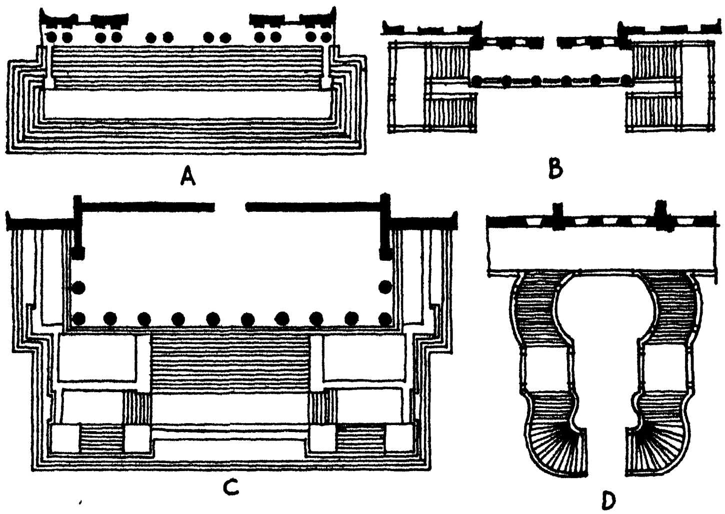


FIG. 61. EXTERNAL STAIRCASES
A = St. Paul's, London *C* = University College, London
B = Kedleston Hall *D* = Cour du Cheval Blanc, Fontainebleau

In designing staircases which are partly round and partly straight on plan, care must be taken to avoid sudden changes in the dimensions of treads. This may be effected by using *dancing steps*, as in Fig. 58 (*B*).

Long straight flights without landings must be avoided, particularly in public buildings. Certain by-laws restrict the number of steps in a flight to fifteen, while there should not be less than three; if fewer are needed to negotiate a change of floor level, a ramp or incline may sometimes be used, in which case the slope must not exceed one in ten.

Modern constructional methods have created great scope in the design of staircases. The treads may be of precast concrete and built into the wall, or the whole staircase may be cast *in situ*: both methods permit interesting shapes and slender dimensions, such as are illustrated in Fig. 59. It will be noted that the metal handrail is also slender and designed so as to emphasize the lines of the staircase. Where space is limited the simple straight flight (Fig. 60 *A*) remains one of the most effective types of staircase, while short flights of steps may be given great interest by the careful design of the handrail (Fig. 60 *B*).

EXTERNAL STAIRCASES. The importance of the difference between internal and external staircases is exemplified by the existence of a French word *Perron*, which applies solely to the latter.

External staircases are usually of a monumental character, used as an approach to a building having its main entrance above the ground level, although many fine examples exist in the gardens of great buildings, as at Versailles.

They are usually designed as elements in the composition of façades, and as such, must be consistent in scale with the building, both in general disposition and in the arrangement of treads and risers Treads should be wider, both for effect and for the minimizing of danger from rain and frost.

The *Perron* may be a straight flight as at St. Paul's, London, parallel to the building as at Kedleston Hall, a combination of these as at University College, or of special shape as at Fontainebleau (Fig. 61).

When of more than one flight, the arrangement should consist of an introductory flight of a few steps, a landing, and then the main approach.

Ramps may sometimes be employed instead of staircases, but they are uncomfortable and

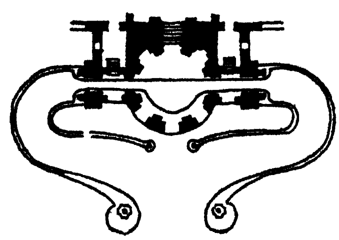


FIG. 62. THE RAMP, THE OPERA, PARIS

even dangerous if steeper than 1 in 10. They are, of course, essential for vehicular traffic, but great care must be exercised in their planning to ensure that the curves and inclines are not too sharp. There is an interesting example at the Paris Opera House (Fig. 62); the curves there, however, render the approach almost impossible for vehicles.

Chapter III—THE SITE

Conditions Imposed by Site. It may be said that, at the beginning of the solution of an architectural problem, the site determines the form the building will take, but that, finally, the building should dominate the site.

Buildings of comparatively small frontage that are enclosed between party walls will not be considered here, since the façade is rarely adjusted to meet any special condition of the site, and at the best can only express very slightly the nature of the plan of a building.

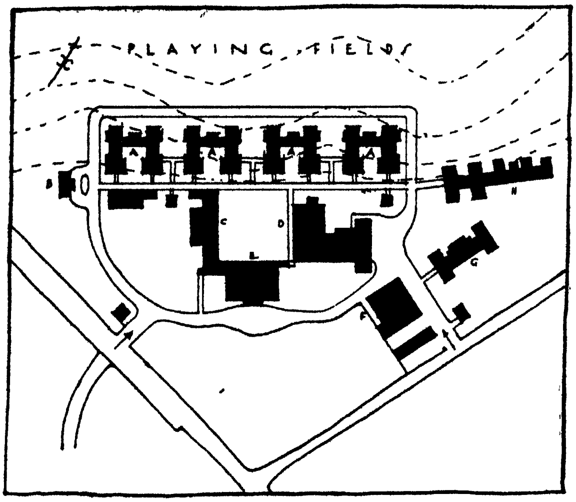


FIG. 63. LAYOUT PLAN OF THE ROYAL MASONIC SCHOOL FOR BOYS, BUSHEY
Henry C Smart, F.R I B A , Architect
A = Houses. *B* = Headmaster's House. *C* = Classrooms. *D* = Dining Hall and Kitchen Block *E* = Great Hall *F* = Laundry and Boiler-house. *G* = Sanatorium. *H* = Infirmary.

The question of selection of site is one with which the architect is frequently faced and, apart from the considerations which will be enumerated, the financial aspect and the suitability of locality will be of importance, but depend more upon a knowledge of affairs than of architecture.

In the consideration of the conditions which the nature of the site imposes upon a programme, there will be the following factors: *size, shape, slope, aspect, prospect, approaches,* and *surroundings.*

Buildings may generally be grouped into two distinct types. *First,* buildings such as schools, hospitals, factories, country houses, etc., which are usually placed on large open sites; and, *secondly,* buildings of national, civic, or municipal importance, which are usually placed on relatively small town sites.

In the former, consideration of the more utilitarian conditions of the site may predominate, while in the latter the creation of a monumental edifice will be the chief object of the designer; always, however, good compositions must satisfy both artistic and material needs.

These groups will be considered separately.

Open Sites. Details of *shape* and *size* will be so varied that it is not possible here to give specific advice. It will be necessary to make adjustments between the requisite degree of isolation and free space around the various buildings in a group, according to the technical requirements of the type of building, and the need for economy of drainage, road-making, and of supervision.

The *slope,* or contouring, of the site will call for special consideration in the disposition of the various units in a group. It is a general rule that the longer direction of the building or group should be at right angles to the slope; or to describe it in another way, buildings should be planned along the contours. This will result in an economy in construction by the elimination of stepping to the foundations, and also in a regular height throughout the group.

The *aspect,* or reference to the points of the compass, will call for special consideration in the planning of certain buildings. For example, it is essential in school planning that classrooms should face, as nearly as possible, towards the south-east; art studios should have north light, and thereby obviate moving shadows; while the playgrounds for the younger children should be arranged where they are sheltered from the prevailing winds. In domestic buildings, the desire for sunlight in rooms at certain times of the day will determine generally the arrangement of the plan, while in some cases the views obtained from rooms or verandas will be of more value.

This question of view, or *prospect*, will be an important factor in the planning of such buildings as seaside and country hotels, where every advantage must be taken of fine views.

Fig. 63 illustrates these points; it will be seen that the Great Hall, Dining Hall, and Classrooms are grouped around a central quadrangle, while the "Houses" are so disposed as to ensure adequate sunlight and fresh air, and at the same time arranged along the contours. The Boiler-house, Laundry, and Isolation Hospital are properly placed as distant as possible, but adjacent to a road for easy and separate access.

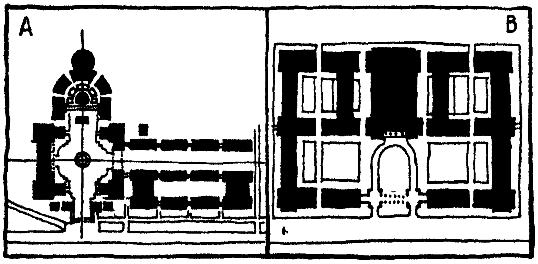


FIG. 64. GROUPED BUILDINGS
A = Layout of a New York State Fair
B = Students' design for a group of University Buildings

The question of *approach* will be very important in factory buildings. A railway siding or canal wharf may be the very reason for the selection of the site, and must therefore be the controlling factor in the placing of the various buildings.

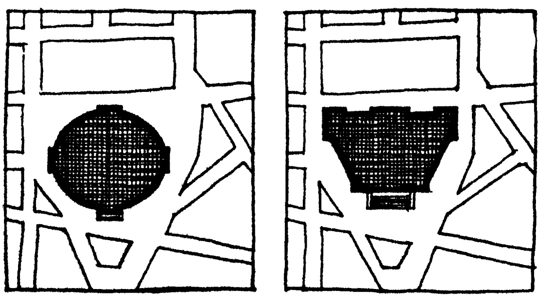


FIG. 65. BLOCK PLANS OF TWO COMPETITION DESIGNS FOR NEW YORK COURT HOUSE

In the design of groups of buildings, such as exhibitions, etc., the desire for artistic effect will involve the arrangement of buildings to close vistas along the various avenues, and the creation of open courts in front of the more important groups. In such cases there must be a compromise between such factors as access, slope, circulation, and artistic effect. See Fig. 64 (*A*).

Monumental Buildings. The consideration of the influence of the site on monumental buildings will show that the approaches and boundaries, and consequent shape of the plan, are the most important external influences upon the design.

Reference has already been made to the question of *scale*, and it has been seen that the actual size of the surroundings will influence the apparent size of the building. Adjoining buildings, in particular, must be studied, and the proposed structure so designed that it will attain its proper status. It must not overpower buildings of national or municipal importance, nor must it be so treated that it loses its own value through smallness of scale when seen in relation to adjacent buildings. Scale is chiefly a matter to be considered in the detailing of the façades; but, as has already been pointed out, simplicity is the keynote of bigness of scale, and in monumental work the simplest plan-form which the site logically permits is the one to aim at. Fig. 65 illustrates block plans of two of the competition designs for the Court House, New York; it will be seen that the simple plan-forms at once suggest a building of importance, and that the relatively large spaces in front of the building provide a setting consistent with the big scale of the building.

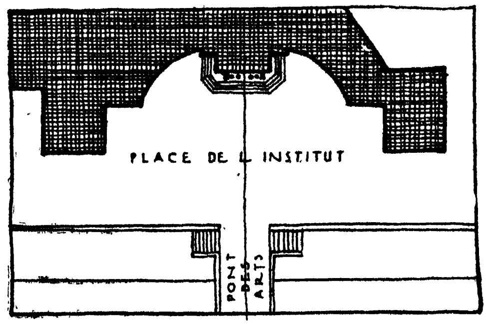


FIG. 66. L'INSTITUT, PARIS

Monumental buildings are normally of the symmetrical type. The placing of the main axis will be the first consideration, and is usually determined by the arrangement of the building to face the main approach. This is illustrated in Fig. 66, although here the axis of an existing building was the determining factor in the placing of a bridge.

On irregular sites, the placing of the main axis is of great importance. A building on a triangular site should, usually, be planned on a centre line which bisects the angle formed by the forked roads (Fig. 67). The various parts of the building should be so arranged that they conform generally to the shape of the site (see Figs. 67 and 68 (*A*)). A point for consideration is the treatment of the boundary wall, or fence ; this should be as subdued as possible, so that it does not invite comparison with the shape and direction of the building.

Where the normal view, or approach, is oblique to the axis, as in Figs. 67 (*C*) and 68 (*B*), the use of a circular, or segmental, feature is of great value ; it will present a reasonable

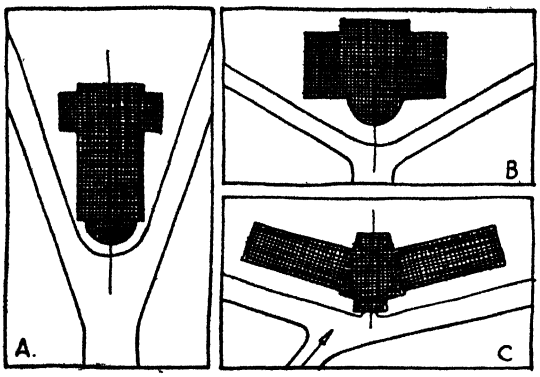


FIG. 67. THE PLAN-FORM VARIED TO SUIT THE SHAPE OF CORNER SITES

frontage from any point of view, besides providing a " hinge " upon which the turn may be negotiated.

Rectangular sites present no serious difficulties in planning. Where minor approaches exist as at *A A*, in Fig. 69, the building should be treated so as to recognize these approaches, and a minor axis introduced which coincides with that of the approach.

As a rule, buildings should not be placed in the middle of the site, the exceptions being those of a monumental character with all façades and approaches of equal importance. The relative amount of space on each side of a building varies in proportion to the importance of that side. In most cases, the building should be set back, leaving an open court, or "place," in front, which provides ample circulation for pedestrian and vehicular traffic, and is also a fitting introduction to an important building (Fig. 69). Frequently, however, the circulation should be of a semi-private character, as in the quadrangle of a university building (Fig. 64 (*B*)).

This question is rather one of civic planning, but must always be considered in conjunction with the design of the building. Fig. 68 (*B*)

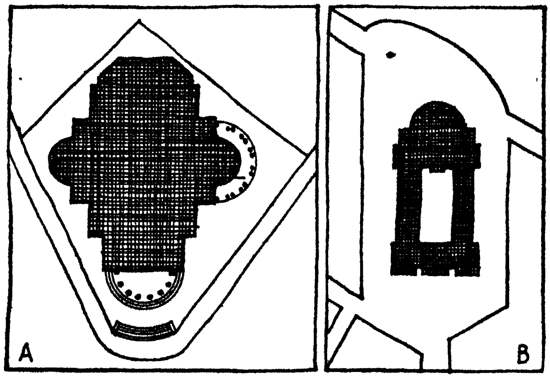


FIG. 68

A = First Church of Christ Scientist, Los Angeles
B = Chapel to the Memory of Marie Antoinette, Paris

shows an extreme case of the provision of a fine setting for an important building by the adjustment of the plan of adjacent buildings.

Not only must the building respond in scale to the spaciousness of the setting, but the approaches also must be bold ; and the spacing

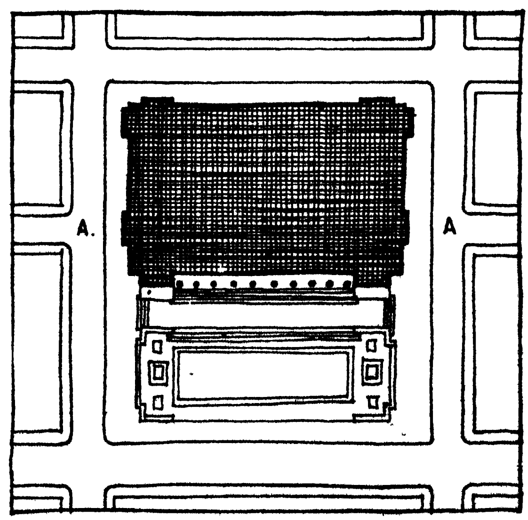


FIG. 69

of the various buildings in a group should be definite, so that when seen from a distance they will not merge into an indefinite mass.

Fig. 70 (*B*) illustrates the approaches to a monument on high ground. The approach for

vehicular traffic takes the form of a winding roadway, or *lacet*, while a grand flight of steps leads direct to the monument. The "going" of the steps must be carefully considered in

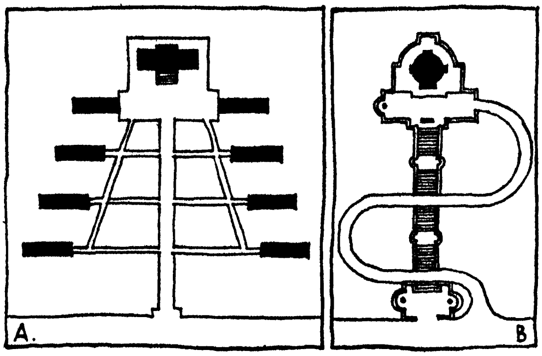


FIG. 70. THE PLACING OF BUILDINGS ON SLOPING SITES

section, and if the main part of the monument is not in view to persons approaching, a minor feature of interest should be placed near the top, to provide a visible introduction to the building.

In Fig. 70 (*A*), a group of buildings on sloping ground is arranged so that the minor parts

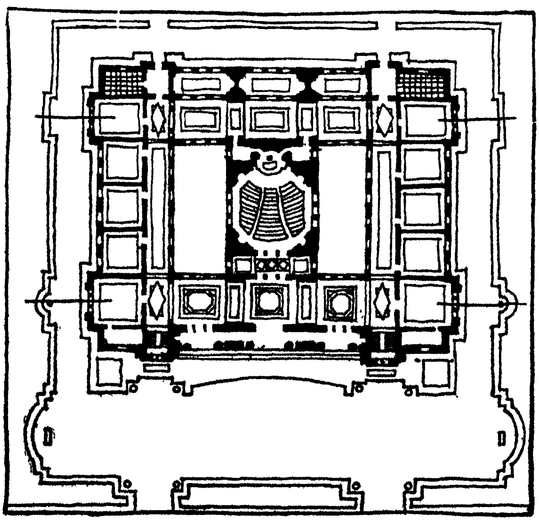


FIG. 71. ADAPTED FROM A STUDENT'S DRAWING

frame in the approach to the dominant feature, providing a pleasing, well-balanced composition, and, at the same time, the views from each are left unobstructed.

Layout of the Site. As soon as the form of the building has been decided, the treatment of its surroundings must be considered. The layout of the grounds must always reflect the importance of the façades to which they relate, and, what is most important, the loss of scale which results from spaciousness carefully considered in designing the various features such as paths, grass plots, hedges, and architectural embellishments. The axes of the plan should always control the layout, thereby establishing a definite relationship between site and building, and also providing for fine vistas, or views, from the principal rooms.

Fig. 71 illustrates a simple example on a

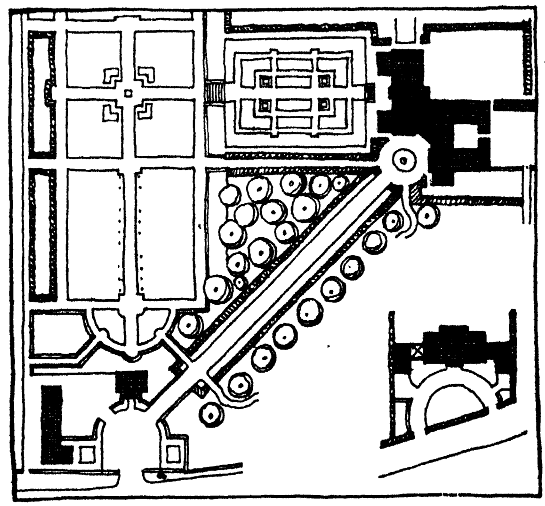


FIG. 72. A GARDEN PLAN
Showing the use of turning points and creation and closing of vistas
Inset: The placing of a small house on an oblique site

relatively small site, while the garden layout in Fig. 72 shows how vistas may be created, and changes of direction negotiated in more open situations. It should be noted that the garden layout near the house is consistent in scale with the building, but that the treatment becomes simpler and bolder in the more distant surroundings.

Monumental buildings should always have a formal layout. The study of the gardens of Italian palaces is invaluable; the treatment near the boundaries is almost free and picturesque, gradually becoming more regular as the building is approached, until finally, a fine flight of steps leads to a paved terrace, embellished with balustrades, fountains, urns, and other decorative features, which introduce the palace itself.

Composition of Mass

The first consideration in the design of a building must always be the plan, and following that the section. These will, to a great extent, control the resultant mass; but it is essential that the various possibilities in the design of façades and masses are visualized, in order that the study of the plan will not proceed along lines which cannot produce a good building.

The first, or general, impression of a building is usually that of its form, or mass: there may be the quiet dignity of a simple, bold mass or façade, a strong contrast of light and shade, or an interesting silhouette, or skyline, resulting from the composition of the various parts of a building.

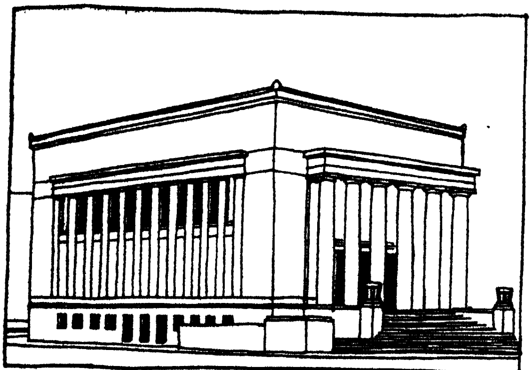


Fig. 73. War Memorial Building, Baltimore

The most lasting impressions of works of architecture are usually those of form: the soaring spire of Salisbury Cathedral, the stately dome of St. Paul's, or the restful dignity of St. George's Hall, Liverpool. These are characteristic, not only of the buildings themselves, but of their purpose.

There are two general types of architectural form—*symmetrical* and *picturesque*; the latter may be dismissed from present considerations, for, as has already been pointed out, it is not usually the result of intention, but of force of circumstances. If such a composition results from the intelligent solution of a problem, the application of the principles of design, which have been outlined, should produce a fine building. The railway station at Helsinki, Finland, is an excellent example of this type of building, as also is the building illustrated in Fig. 2.

Symmetrical forms may produce three general types of mass—

1. The simple geometrical mass.
2. The mass resulting from group plans, with projecting features, usually extended in a horizontal direction.
3. Tall buildings; these are considered separately, since the factors determining the design of their general form are different from those in Chapter II.

The study of domestic work will also be considered separately, although similar principles are involved.

The design of façades in detail will be dealt with in a later chapter.

Simple Masses. The design of the simple geometrical mass will usually be governed by the nature of the plan. If the accommodation consists chiefly of one large unobstructed space, the construction and decoration of the roof will frequently provide the keynote for the design, as, for example, the domed churches of the Renaissance, in which the plan form is as much a structural necessity to the dome as an exigency of planning. In other cases, when the uniformity and simplicity of the mass is the result of the architectural screening of the plan, the roof may be of minor importance, and the design will concern the treatment of windows and wall surfaces. The relationship between the various façades is of vital importance. If adjacent sides are of equal size and similar shape, the resultant mass may be dull and uninteresting, unless special distinction is given to one side, thereby establishing a definite front to the mass. The value of the portico to the building illustrated in Fig. 73 will be obvious.

Mass Due to Group Plans. The composition in mass of buildings of the second type is governed almost entirely by the requirements of the plan. As will be seen later, breaks will express externally the disposition of important rooms, staircases, etc., and effect will depend largely upon the composition of these elements into interesting façades. The simple example illustrated in Fig. 74 illustrates this point very well; it will be seen that the organism of the plan is well expressed in the mass, the two staircase towers and blank end walls to the classrooms being admirably arranged to punctuate the main façade.

The study of the architecture of the past indicates that pyramidal structures embody the essence of unity and stability. But space enclosing walls must be vertical, and this expression must be obtained by the grouping of rectangular masses. Although the programme may not call for a culminating feature, such as a

dome or tower, the buttressing of the dominant mass by the subsidiary masses will produce similar effects. The introduction of a dome or tower involves similar considerations (see Fig. 75), but if this feature is set back considerably from the main façade, the latter must be

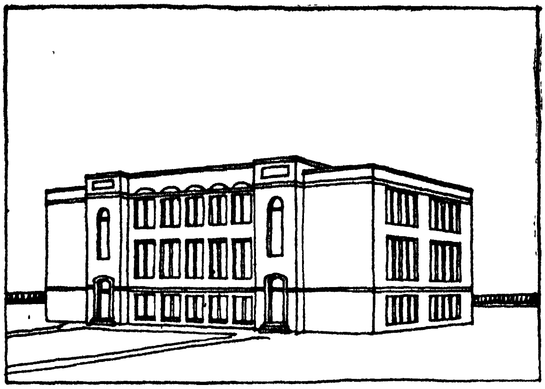


FIG. 74. SCHOOL AT WHITEHALL, U.S.A.

adjusted in detail so as to suggest the base of the dominant mass and express its stability. Nothing is less satisfactory than a tower or dome which rises unannounced from behind a roof or parapet.

It is also important that foreshortening in perspective is anticipated, and after preliminary elevations have been prepared, the height of important features, which are set back, must be adjusted according to the normal levels and

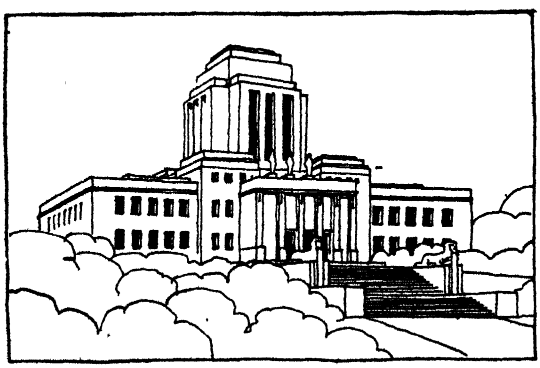


FIG. 75. AFTER A DESIGN FOR A PARLIAMENT HOUSE, BY E. SAARINEN

direction of important viewpoints. Similar considerations will also affect the pitch of a roof over a tall building, if it is an important element in the composition.

The economic and aesthetic values of simplicity are responsible for the creation of many interesting plan forms, usually on a geometrical basis. The newer tube stations in North London are examples worthy of close study, and the building illustrated in Fig. 76 indicates the manner in which a comparatively large building with a multiplicity of minor elements in its plan may be developed as a simple but interesting mass.

SOLIDS AND VOIDS. It will be well in passing to comment upon the proportions of solids and voids in monumental buildings. These should be consistent throughout, special care being taken to avoid deep recesses on the same axis

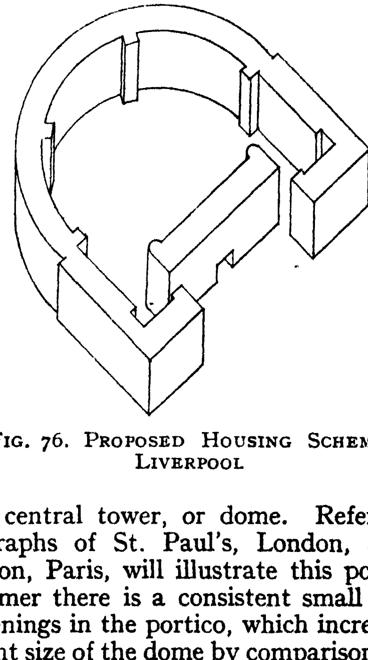


FIG. 76. PROPOSED HOUSING SCHEME, LIVERPOOL

as the central tower, or dome. Reference to photographs of St. Paul's, London, and the Panthéon, Paris, will illustrate this point. In the former there is a consistent small scale to the openings in the portico, which increases the apparent size of the dome by comparison ; while in the latter the deep shadows under the great projecting portico are not suggestive only of weakness, when seen immediately in front of the dome from the main approach, but the scale of the portico is magnified in perspective, to the detriment of what is really the dominant feature—the dome.

Tall Buildings. Reference to tall buildings will automatically lead to the consideration of American buildings, the study of which is valuable. The chief principle of design, in the consideration of tall buildings in particular, is one already referred to.

All structures should have a base, a middle, or containing part, and a roof, or other protective crowning feature. Despite any real

stability resulting from the construction, these three divisions should be clearly evident in the architectural treatment, always propor-

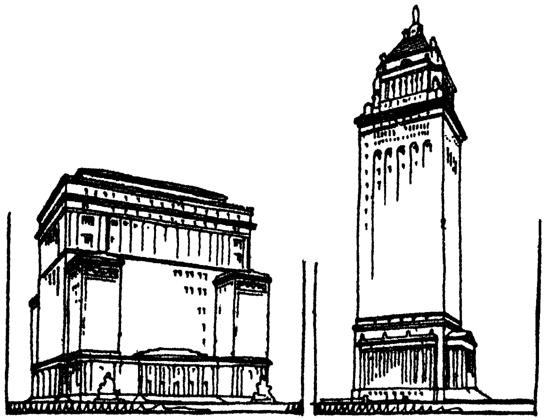


Fig. 77. After Competition Designs for the Court House, N.Y.

tionate to the total height of the building. See Fig. 77.

In buildings of ordinary height, the important floor levels may be marked by horizontal features such as string courses, or by similarity of treatment throughout a range of windows, but in tall buildings, individual floor levels should be merged into the three main divisions, both for

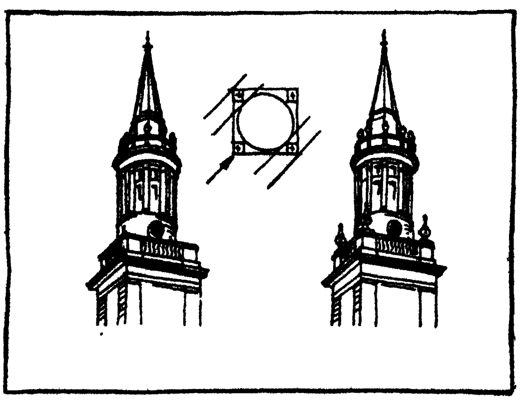


Fig. 78. Tower, All Saints, Oxford

the avoidance of monotony, and the expression of the true scale of the building.

The silhouette must always be carefully considered from all points of view, not only in tall buildings, but in all tall structures such as clock towers, campaniles, and domes. Elevational appearance will be very misleading where the plan changes shape, or size, at intervals. Excellent illustrations of this may be found in many of the church towers and spires designed by Wren, Gibbs, and others. Fig. 78 shows the upper part of the tower of All Saints, Oxford, in one case as built, and in the other with vases removed. It will be evident that, although the square and circular parts have almost equal width in elevation, an oblique view will show a sudden and disturbing break; in the example illustrated this is subtly relieved by the use of a decorative feature placed on the corners of the square part.

A most interesting development in architectural massing has resulted from the introduction of zoning laws in New York. These regulations control the height of buildings at

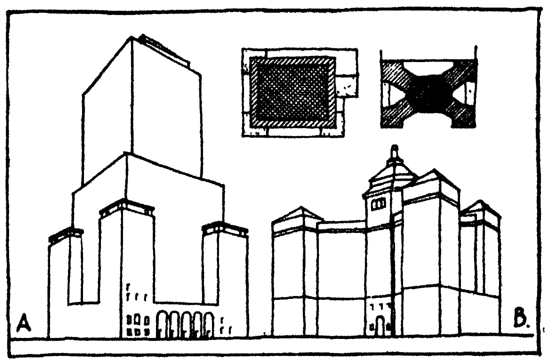


Fig. 79
A = Shelton Hotel, N.Y. *B* = 5th Avenue Hospital, N.Y.

the building line in proportion to the width of the street, and permit additional stories, which must be set back inside a line drawn from the centre of the street passing through the top of the front wall.

The outcome has been a new and simpler style, dependent for its effect upon fine massing and interest in silhouette (Fig. 79 (*A*)). In these buildings, decoration is concentrated at those points which require emphasis, that is the base and the crowning feature.

The composition of the building illustrated in Fig. 76 is unusual. Here the requirements of light and air, and a restricted site, were factors which produced an interesting plan-form and consequent mass.

Interest in massing may also result from plan-forms designed to place as many rooms as possible upon a street front; an example of this is to be seen in Devonshire House, London, in which an interesting mass results from the frank expression of the plan.

Chapter IV—FAÇADES

ALTHOUGH the general impression of a building is produced by its mass, the latter is very largely dependent upon the proportioning and detailing of its façades.

It will be evident that there are two general types of façade—those with a uniform frontage, and those with breaks and projecting features.

The former derive their effect from the modelling of wall surfaces and the composition of door and window openings, while the latter are governed chiefly by the proportioning and disposition of the component features, but also, of course, by their detailing.

It has already been pointed out that the plan and the section are all-important factors which control the design of façades. In many buildings, dimensions are rigidly fixed by the consideration of fittings and furniture; in a school, for example, by the spacing of desks, and in a hospital by the spacing of beds, while the height of the various stories is a compromise between economy, effect, and efficient lighting and ventilation.

Generally, however, the dimensions of plan and section are capable of a certain amount of variation, and adjustments are possible which allow considerable latitude in the design of façades and the resultant massing.

It is at once evident that the exigencies of planning may demand that certain features project beyond the general frontage. Breaks may also result from the desire for monumental interiors, as in Fig. 80; in *A* it is seen that the regular spacing of the windows does not permit a good interior, as the space between the window and flank wall is too small; while in *B*, not only does the break give considerable freedom in the design of the interior, but it also expresses in the elevation what is possibly an important room. Apart from this consideration of interiors, breaks are often required to relieve monotony in long unbroken façades, but they are always a compromise between the material requirements in plan and section and the desire for effect. They may occur as pavilions to punctuate the long wing of a building, as in The Louvre, Paris; to create features which close vistas (Fig. 69); or to establish points of interest and utility, such as occur at the main and subsidiary entrances to a large building.

The close relationship between the plan and the façade is particularly evident on an open site. Rarely are the façades of equal importance: there will be a main or entrance façade; those on the sides, similar in detail but of less

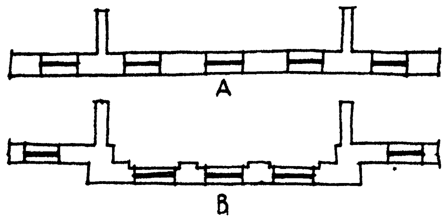


FIG. 80

importance; and at the rear, one of more or less importance than the sides, according to the nature of the programme and the importance of the streets and approaches.

It will be seen, then, that façades, except those of buildings having a restricted street frontage between party walls, are determined primarily by the plan; but since external effect will be anticipated from the beginning of the solution of a problem, the composition of façades is a factor in planning which must be constantly under review.

Façades with Breaks or Projecting Features. Projecting features gain in prominence in perspective, while long projecting wings in front of a building create a vista which must lead to the focal point of the composition.

It is therefore essential that, though façades may be considered and drawn in direct elevation, their effect in perspective must always be visualized in their conception.

Façades with a broken front are of infinite variety. They are composed of one or more elements which might be described as follows: *Principal Mass*, *Subordinate Masses*, *Links*, and *Appendages* (see Fig. 81).

It is possible to group them into three categories—

1. Façades with a middle projection and wings.

2. Façades with end pavilions and a recessed uniform link.

3. Façades combining the above two types. The first is usually employed to give emphasis to a central entrance; the second on lateral elevations, although there are many fine examples in which end pavilions are used to punctuate a colonnaded or arcaded entrance façade, as in the Opera, Paris, or to accentuate two entrances of equal importance as in the Admiralty Buildings in the Place de la Concorde, Paris. The third arrangement is only possible in the long façades of monumental buildings, such as, for example, Hampton Court Palace, and Chelsea and Greenwich Hospitals.

FIG. 81. THE CUSTOMS HOUSE, DUBLIN

Façades with curved wings may be very effective, as in the church of Holy Trinity, Kingsway, and L'Institut, Paris (Fig. 66); the plan, however, will be difficult to handle and the work costly.

Architectural design cannot be controlled by hard and fast rules. It is a system of compromise between *material* and *artistic* requirements, reflecting always the critical intelligence of the designer.

For that reason a number of diagrammatic elevations have been given in Fig. 82, a brief criticism of which will serve as a guide to the design of other compositions.

It will be seen that each of the diagrams is composed of three features of varying proportions and shapes, some intentionally bad.

In *A*, the central feature is too small and fails in that, instead of providing a dominant feature, it cuts the façade into two parts. If essential to the programme, such a portico would be better if lower, as in *B*, thus reducing the composition to a simple mass with a small subordinate feature. In *C*, there are three equal parts; equality is uncertain and uninteresting, and a pronounced variety in surface treatment would be required to give interest and prominence to the central feature. *D* is a sound composition in which the appendages are quiet and give interest to an otherwise uniform façade. In *E* is illustrated a most serious defect in massing; the central recess leaves two equally prominent features with no focal point of interest. *F* is similar to *C*, but here the end features gain prominence in perspective because of their projection; a solution of this difficulty is illustrated in *G*, in which the side masses are broken up into small parts which are less important and striking than the colonnaded portico in the centre.

It should be noted, however, that a "parti" which calls for the breaking up of the elements into still smaller features does not promise a sound mass, and is better abandoned in its early stages. An elevation which is worried with small detail usually betokens a worried plan, which is not the best solution of a problem. *H* is a frequently used composition, in which the end pavilions provide definite stops to the colonnade.

It will be seen that in these diagrams the height of the compositions is uniform; but the

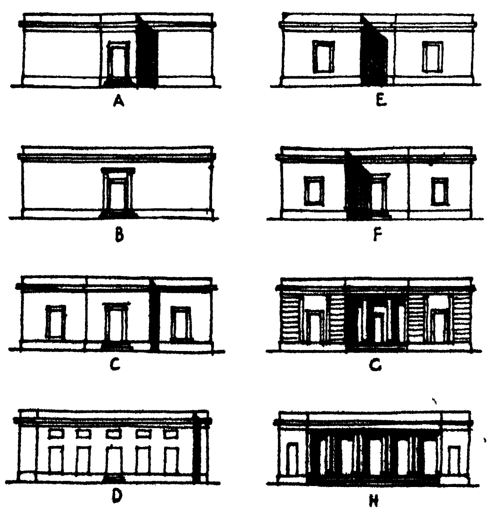


FIG. 82

programme may sometimes require additional height to some parts, while alternatively, it may be desired to give importance to some elements by increasing their heights by means of pitched roofs, parapet walls, attic stories, etc.

Such variations in height may accentuate the defects referred to in Fig. 82, or they may bring interest to the silhouette of a dull mass

and decision to the proportion of the component features.

A further series of diagrams is given in Fig. 83, in which features of similar widths to those

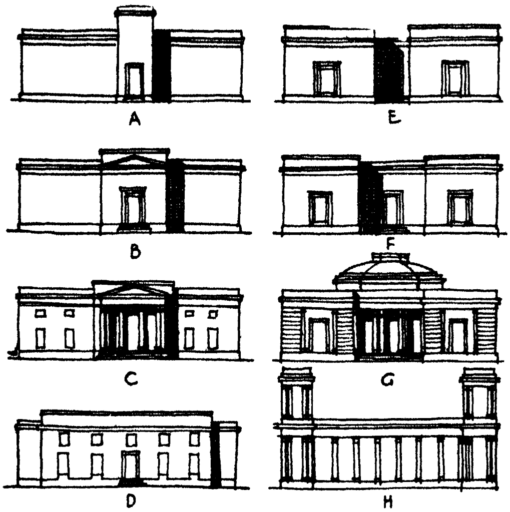


FIG. 83

in Fig. 82 have varying heights. While the central feature in *A* gains in importance through increased height, it is still too small to dominate the composition and is not sufficiently tied in to the main mass. In *B*, the hesitating proportions laterally are removed

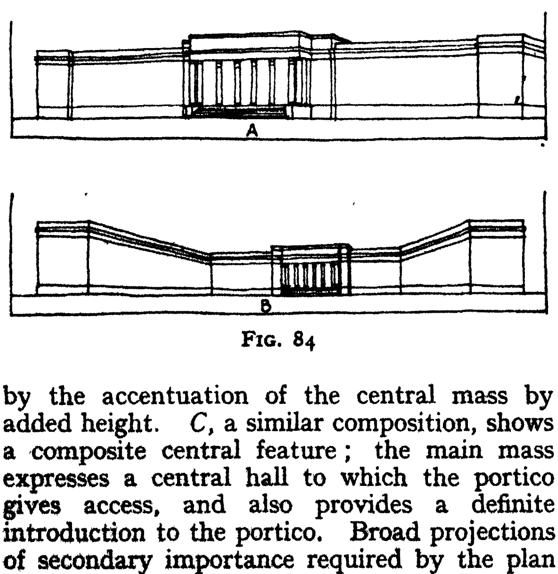


FIG. 84

by the accentuation of the central mass by added height. *C*, a similar composition, shows a composite central feature; the main mass expresses a central hall to which the portico gives access, and also provides a definite introduction to the portico. Broad projections of secondary importance required by the plan may frequently be broken up in this way, and thus recognize the scale set by the dominating feature. The façade illustrated in *D* has been made interesting by the added height to the central mass. Diagrams *E* and *F* should be compared with Fig. 82 *E* and *F*, when it will be seen that the added height to the end features has accentuated the duality of the compositions. Elevations of this type are difficult to handle, although the presence of an obvious dominant, as in *G*, may justify the central recess that gives access to the space which the dome expresses. In *H*, the additional stories to the end pavilions are too heavy, and the end masses in consequence compete very strongly with the central colonnade.

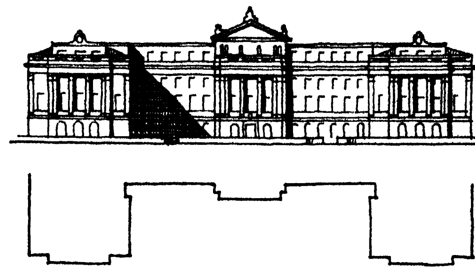


FIG. 85. SOMERSET HOUSE, LONDON
West Façade

The break is very sudden, and the silhouette restless.

Besides proportions in true elevation, it is necessary to consider those which result from the projection of various features. Since projecting features gain prominence in perspective, care must be taken that only important features shall have pronounced projection beyond the general frontage line.

A number of features of equal projection will usually be monotonous. Either the central mass should be accentuated, by projection as in Fig. 84 *A*, or a forecourt created by projecting wings as in Fig. 84 *B*. The plan must determine which of these general forms is to be adopted; it must not be permitted to require both, and careful discrimination must be made between simple breaks and projecting wings. When the amount of projection approaches or exceeds the width of the feature, it will require careful treatment, and the flanks of the projection will call for special consideration (see Fig. 85).

The general effect of façades will not only depend upon dimensional proportions. Attention may be focused upon the dominant by means of strong contrast of light and shade,

as in Fig. 86, or by the introduction of interest in shape, as in the pediment in Fig. 85.

Façades in Detail. So varied are the problems in the design of façades in detail and the methods available for their solution, that it would be futile to attempt to analyse all types. Their design resolves itself into the composition of

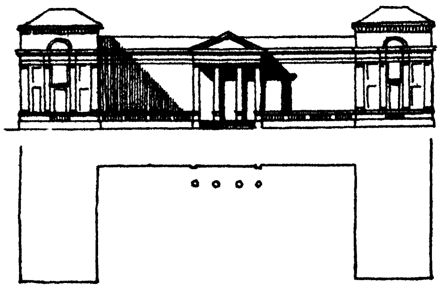


FIG. 86. TAYLOR AND RANDOLPH BUILDINGS, OXFORD

those elements which have already been briefly discussed, and the principles of design which have been outlined constitute the basis of such design. It will be valuable, however, to consider briefly the general characteristics of the more common types of composition.

The detailing of the elements which make up the complex façades just referred to should always reflect their importance in the composition. The greater degrees of interest, either by contrast of light and shade, in shape, or in enrichment and colour, should always be reserved for the more important points, and the remainder treated in a simpler manner so as to provide a suitable foil or background; see Fig. 81, and many other similar buildings.

In the design of simple façades, or of the component parts of more complex compositions, the first consideration must always be the *structural nucleus*, which is, of course, determined by the requirements of the programme. Frequently it is impossible to obtain a symmetrical disposition of windows and supports. In such cases, it is usually safer to accept what the plan and section dictate, and, by creating a point of interest by a simple break, either in frontage or in skyline, introduce a feeling of reason and order into the composition: Figs. 87 *A* and *B*. It is invariably the better course to permit such an elevation to express a sound plan than to distort a plan behind a symmetrical but nevertheless sham façade.

Usually, however, a more or less symmetrical disposition of units can be logically evolved out of the programme, and points of support, whether brick or stone piers or walls between openings, or a skeleton of steelwork, will be regularly spaced throughout the façade. These lateral bays, together with the vertical subdivisions determined by floor and sill levels, constitute the *structural nucleus* from which the design of façades *must* develop; it may be called the *grid*. Apart from the consideration of materials to be employed and the essential areas of windows, etc., the final treatment will be uppermost in the mind of the designer. Artistic prejudices, the nature of the programme, or local tradition, may involve an excursion into one of the historic styles; while on the other hand circumstances, either the need for economy, the desire for adventure, or the modern characteristics of the programme, may permit or even demand a treatment which is often so vaguely referred to as " Modern."

In the former case, a sound appreciation of the reason behind historical architecture is essential, and it is well for the inexperienced to treat tradition with respect. Those elements of architecture which have stood the test of centuries are not to be thoughtlessly abandoned for something which may not even have reason to commend it. The new must not be sought

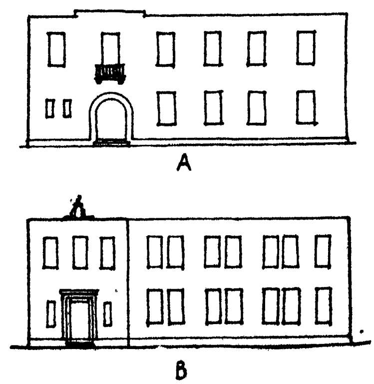


FIG. 87

for its own sake: a *modern* treatment should result from the desire to create fine architecture which is the logical outcome of the use of modern materials and the expression of modern civilization, rather than the conscious scorn of tradition.

It has already been pointed out that, apart from questions of style, the design of façades is more than the mere mechanical arrangement of solids and voids. There is always sufficient

latitude in the programme to permit minor adjustments to proportions, and well arranged but simple wall surfaces may produce buildings just as impressive as those which are highly decorated, although the former will often

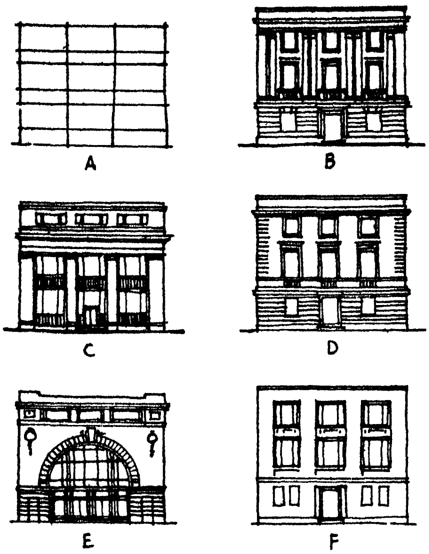


FIG. 88

demand of the designer a higher degree of artistic skill than the latter, which are too frequently the result of superficial examination of historic architecture. To return to the structural nucleus, it is always good practice to draw this as the basis for design, and then to consider the disposition of the elements or motives which are to be employed. The critical examination of the sets of diagrams which have been given will serve as an indication of the lines along which the thoughtful design of façades might proceed. Students will do well to make a number of similar diagrams for the many arrangements of bays and floor levels that present themselves, developing their ideas as a result of the study of historic architecture or of modern materials and conceptions of form and expression.

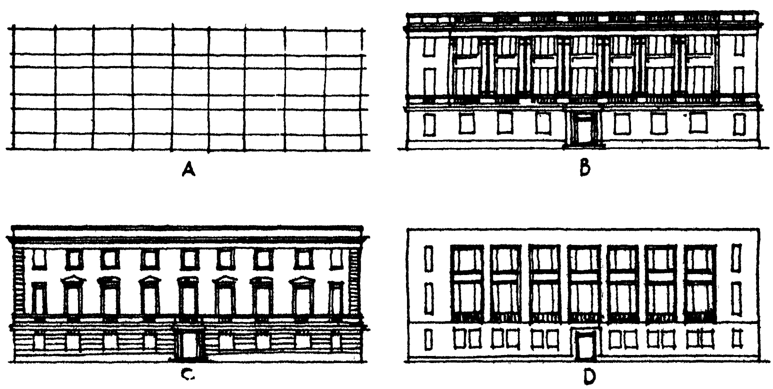


FIG. 89

In Fig. 88, the first diagram, *A*, shows the grid of a small façade, which is developed in a number of ways, the salient points involved being as follows. In *B*, the employment of the Orders involves the introduction of pilasters at the ends in order properly to punctuate the façade, while a simple ground floor expresses a base for the superstructure. The spacing of the bays and the height of the stories to be incorporated in the "Order" will determine whether single or coupled columns are required. The entablature to the Order is insufficient in itself as a crowning feature, and a parapet wall has been added. In *C*, it is presupposed that the façade contains an entrance to a banking hall behind the rooms on the frontage, and the *scale* of the façade is increased accordingly; a sturdier Order is employed, and the floor levels lose their individuality and small scale in the expression of the scale of the main feature—the banking hall. In *D*, an astylar treatment is adopted, the limits of the façade being defined by means of the rusticated quoins. The end windows are kept some distance from the end so as to avoid a feeling of overcrowding which results when a sequence of features is stopped too suddenly. The façade of the Farnese Palace (Fig. 14) suffers because of this.

In *E*, an important entrance is expressed by the introduction of a large opening which is the dominant feature in the composition, but care must be taken to provide abutments that look strong enough to support the arch despite any hidden construction. Such a treatment obviously involves the adjustment of the grid, but in the example shown it may well be that the provision of a wide imposing entrance, as to a cinema, is of more importance than a too rigid consideration of economy in construction.

In *F*, all detail is eliminated, and the design resolves itself into a composition of solids and voids. The façade is punctuated by the broad wall surfaces at the ends, and similarly, a simple parapet provides a crowning mass sufficient to define the limits of the composition.

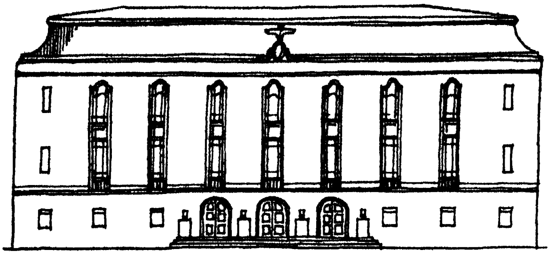


FIG. 90

In Fig. 89 simliar treatments to a larger façade are indicated. It is evident that there is greater latitude for variation in detail, and in many cases variety will be necessary to create interest. The first treatment, *B*, involves the use of the Orders, but here the façade is long enough to require a substantial punctuation and there are sufficient bays to permit of a different treatment to those at the ends while leaving enough in the centre to maintain

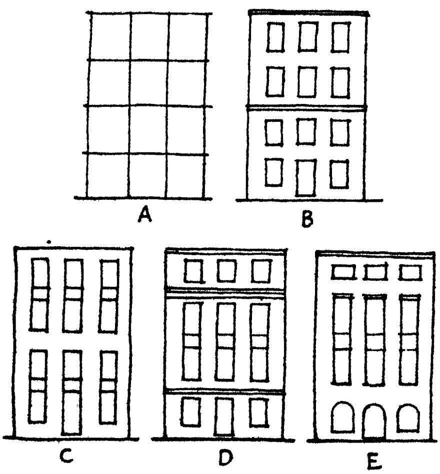


FIG. 91

continuity or rhythm. This question of number will be referred to again later. In *C*, an astylar treatment, it is possible to relieve monotony by varying the pediments over windows; while the number of bays permits further variety in the end windows which are smaller, thus announcing clearly the completion of the composition. A simple treatment is again employed in *D*, in which the only departures from a uniform arrangement of solids and voids are the smaller windows which punctuate laterally and the emphasis of the entrance by a simple architrave.

A further illustration of these points is given in Fig. 90, where it is anticipated that the programme permits a preponderance of wall surface over window openings, and interest results from the composition of shapes. Attention is focused on the doors by the variety in shape, and the general squareness of line is relieved

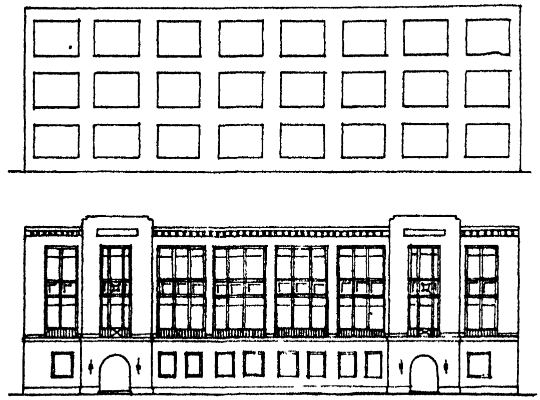


FIG. 92

by an interesting roof, which is an essential element in the composition.

In façades of a larger number of stories in height, difficulty may be encountered in the location of horizontal breaks which will prevent monotony. In Fig. 91, a number of diagrams illustrate a line of reasoning in this matter; *A* is the grid from which the façade is to be evolved, while *B* and *C* indicate the lack of unity which invariably results from the actual or suggestive breaking up into two equal parts. Good results are best obtained by the indication of the three parts already referred to: *base, filling*, and *crowning feature*, either definitely by means of string courses, etc., as in *D*, or more subtly by the linking up of the intermediate windows and varied treatment of the remainder as in *E*.

It will be well at this stage to point out that even uniform façades must be studied in the third dimension. Nothing influences a façade more than the depth of reveal, or the thickness of a pilaster or column, and the consequent depth of soffit of the entablature. Bearing in mind always the need for avoidance of waste, both in wall thickness and in floor space,

the apparent thickness of a wall as evidenced in returns and reveals must alway be consistent with the weight of the general modelling of the façade in direct elevation.

The conditions of the programme may some times produce long and low façades, as in Fig. 92

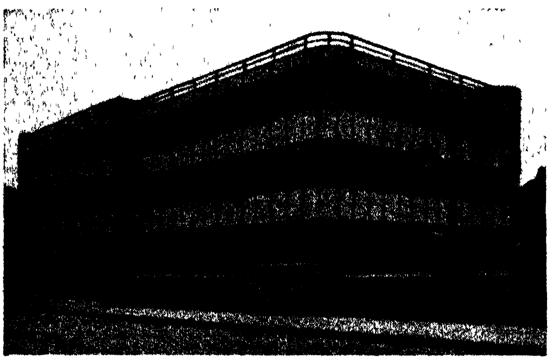


FIG. 93. UNIVERSAL HOUSE, LONDON
Courtesy of "Building"

This may be given interest by the introduction of vertical breaks which relieve monotonous length, or alternatively, the designer may create interest by emphasizing the horizontality; this results from modern constructional methods in which the actual vertical supports are behind the façade. Although each case must be determined on its merits, it will usually be found that uniformity of scale will result from the confining of decoration to either the small parts or the large; but never both.

Reference has been made to the loss of scale which results from a multiplicity of small elements. This may be avoided by linking them up in the detailing of the façade by incorporating a number in a single framework or by the use of a continuous balcony as in Fig. 96. In this example, other factors which contribute to the big scale are, first, the indication of *three* bays by the use of three dormers and three important windows on the ground floor, and, secondly, the employment of fine, simple, but large, piers at the ends of the façade. It is also interesting to note that the rusticated base has been cleverly terminated at the springing of the arches instead of at the floor level, in which latter case the wall surface would have consisted of two parts more or less equal and therefore be lacking in interest and smaller in scale.

It not infrequently happens that the number of bays resulting from the logical working of a programme is an even number. This may be disturbing to the designer, who makes a fetish of absolute symmetry and seek to place a complete unit in the centre of a composition rather

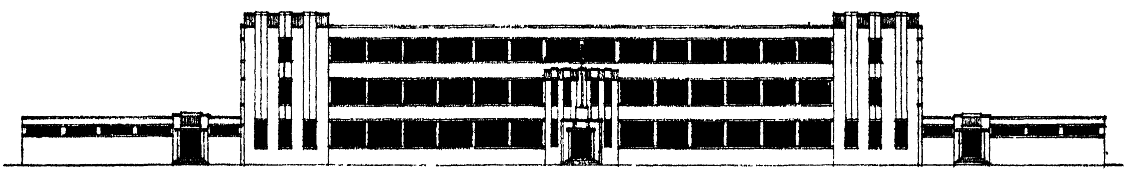


FIG. 94. TECHNICAL COLLEGE, NEASDEN

the wall face, and the façade resolves itself into horizontal bands of windows and aprons or screen walls, as in Figs. 12*B* and 93. Another modern treatment is suggested in Fig. 94, in which the classroom windows are almost continuous, with pavilions at the ends of the main façades to provide punctuation. These pavilions have no structural significance but they give definite interest to the building.

Although involved plans usually produce façades with breaks, both for effect and utility, there are many examples of simple façades which express a fine plan without having projecting features (see Fig. 95). When the building contains rooms of greatly varying size and importance, the chief difficulty will be the maintaining of the same scale throughout than a line which represents a division. While it is true that a void or a bay is as a rule preferable, it is unwise to spoil a plan in order to secure this; and, in any case, a sufficiently large number of similar units will lose individuality or number in the rhythm or sequence which runs through the group, and only a mechanical examination as distinct from artistic impression reveals the fact that the exact centre of the composition is a solid, such as the pier in Figs. 92 and 94.

Domestic Buildings. Although the design of façades and the massing of buildings of a domestic character are subject to considerations similar to those involved in the other types referred to, it is evident that the invariable use of a relatively important pitched roof, and the

greatly varying textures and colours of the materials employed, are elements which call for especial study.

Façades of domestic buildings are generally of two types: *Formal* and *Picturesque*. The formal, or symmetrical, type is admirable when reasonable, but is difficult and very often illogical in small buildings, where there are usually many varying elements. Many pleasantly formal façades to small houses have been produced, but only by balancing such widely differing features as drawing-room and larder windows! The decision as to the desirability of such an expedient must be made by the designer in individual cases.

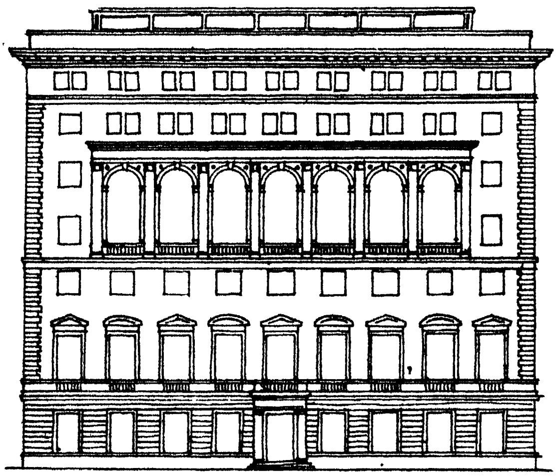


FIG. 95. THE ATHLETIC CLUB, DETROIT

The formal treatment will involve the consideration of the principles already referred to.

Since utilitarian and economic considerations predominate in the planning of houses, it necessarily follows that the plan-forms which result will frequently produce an assymmetrical mass which is not capable of a great amount of variation. But, in many cases, an anticipation of the ultimate mass will ensure that the design will proceed along promising lines. One of the most important considerations in this type of design is the provision of an obvious principal mass. By comparing Fig. 97, *A* and *B*, it will be seen that the former, through the equality of the two wings, lacks a definite sense of direction, while the latter arrangement provides an obvious dominant with a subordinate mass, the ensemble having a definite sense of direction. Similarly, there should be a definite predominance of one element over the others; either the wall surface or the roof with its subordinate elements, such as chimneys and dormers, should be the more important; equality is usually uninteresting (see Fig. 98).

Many domestic buildings are ruined by the desire to introduce the "picturesque" atmosphere by means of uncontrolled variety in wall treatment. That variety is both legitimate and desirable in the avoidance of monotony in the long rows of similarly planned villas cannot be denied, but it is to be regretted that it is so frequently attended by an utter lack of appreciation of colour and of proportion. While the subtleties of colour cannot be discussed here, it is possible to generalize on the proportionate treatment of surfaces. In Fig. 99, the first figure *A* shows a popular type of elevation in which the respective areas of roof, rough-cast, and brick-facing are monotonously equal. In *B*, the "high-waisted" treatment is possible but often too worried for so small a building. The treatment illustrated in *C* is

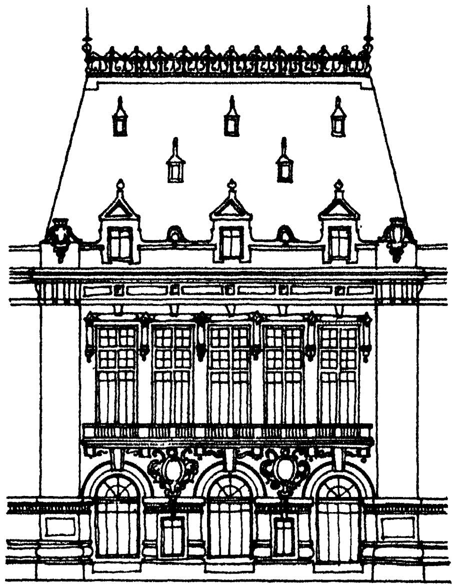


FIG. 96. FROM A DESIGN FOR THE HÔTEL DE VILLE, SENS, FRANCE

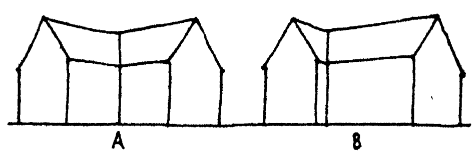


FIG. 97

much better, in which one surface treatment is employed with a simple break at the plinth, representing both an aesthetic " base " and a useful protective treatment against dampness.

Frequently there are a number of units of different spans to be roofed; there is usually

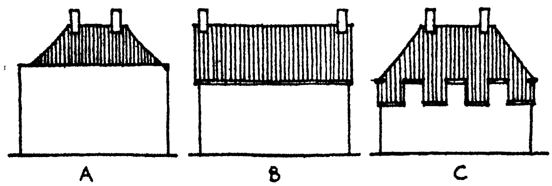


FIG. 98

A = Predominance of wall surface
B = Equality and lack of interest
C = Predominance of roof and accessories

plenty of latitude in the choice of method, viz., gable or hip, or a combination of these. It is difficult to lay down rigid rules, but the more restful results are obtained when the relative importance of the elements is recognized, and

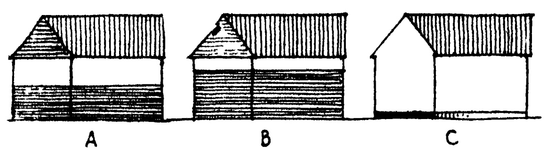


FIG. 99

variations made accordingly. In Fig. 100, *A*, it is seen that the three similar dormers are gabled, while the main roof is hipped back above the ceiling level, and in Fig. 100, *B*, the prominent projection is gabled, while the main roof and dormers are hipped; in the case of the dormers, such treatment not only avoids competition with the main gable, but prevents a certain spottiness, which sometimes happens when the gables in dormers are rough-cast, or in any other way given distinction.

Interest and character may often be given to façades by the acceptance and proper use of practical requirements. In Fig. 101, the upper elevation faces north and naturally contains few windows: these are skilfully arranged and the plain wall surfaces provide an excellent foil or background for a fine entrance door. The lower or south elevation contains many windows; these are pleasantly arranged and become the dominating features.

In the detailing of the elevations of domestic buildings little can be added to the brief advice already given, for although the *motifs* employed may be both different in detail

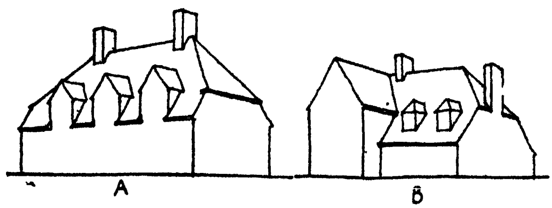


FIG. 100

and in scale from those on commercial and similar buildings, the principles involved are the same.

In conclusion, it must be emphasized that those points which have been outlined are only

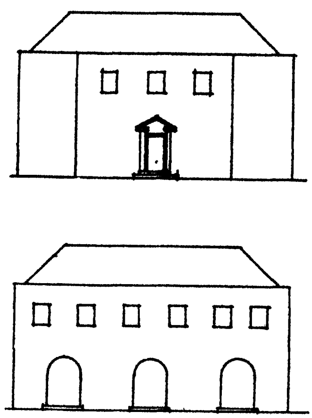


FIG. 101

the salient characteristics of façades in general, and must not be taken as the basis of a rule-of-thumb method of architectural design. Powers of design can only be cultivated by the constant study of buildings and the critical examination of reason and result; for no two sets of conditions are alike, and the only real solution is always the one which is the logical outcome of the careful study of the programme.

Chapter V—PRINCIPLES OF PLANNING

FIRST considerations in the design of a building are almost invariably concerned with the plan, the plan being an arrangement of rooms and approaches which provides the most satisfactory disposition of the accommodation required. In the lay-out of the plan many factors must be considered, some of which have already received

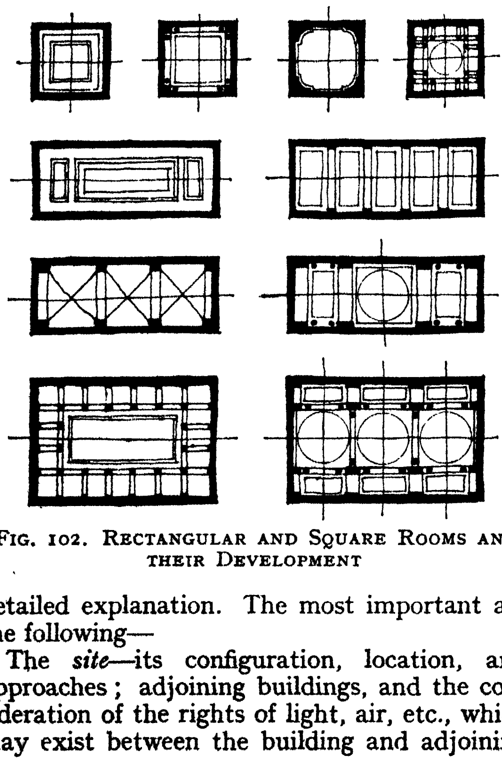


FIG. 102. RECTANGULAR AND SQUARE ROOMS AND THEIR DEVELOPMENT

detailed explanation. The most important are the following—

The *site*—its configuration, location, and approaches; adjoining buildings, and the consideration of the rights of light, air, etc., which may exist between the building and adjoining owners.

The *programme* of the requirements of the client, including not only such factors as accommodation and cost, but also the observance of the many enactments which control the design.

The *method of construction and materials* to be employed, both in the erection of the carcase of the building and in the detailing of ornament, which must be in sympathy with the material in which it is executed.

The *massing* which results from the disposition of the elements in the plan.

The *treatment of façades*.

The plan should also take account of important mechanical adjuncts of the building, such as the ventilating, heating, and lighting systems.

It is possible to summarize the two main aspects of planning as the practical requirements which must be provided for, and the foundations for the aesthetic treatment of the exterior and interior.

ELEMENTS OF PLANNING

A plan may consist of one simple unit, such as a shelter or loggia, which has no subdivisions and only external means of access, or it may consist of a collection of units with the necessary access and intercommunications.

Before studying the possible grouping of these units, it is well to examine the considerations which govern the design of the individual elements of planning.

Rooms. A room must exactly fit the purpose for which it is designed. This sounds a perfectly obvious statement, but in practice it is by no means so straightforward.

1. It must first provide for the construction of the floors or roof over, thus involving the introduction of piers, stanchions, or solid walls.

2. It must next have sufficient external wall or roof area to provide adequate lighting.

3. It must be suitable in shape for the purpose for which it is intended, and, in the case of rooms provided for special uses, must have a floor surface which is most suited to that purpose; thus the dining room must recognize the dining table as its salient *raison d'être*. Bedrooms must provide for a bed or beds, a theatre for seating, and a church for the maximum number of members of the congregation conveniently placed for hearing the service or the sermon.

In providing for fundamental requirements, certain plan-shapes will automatically come into existence, but these shapes may be adjusted to a certain extent; thus a square plan will provide for a circular dining table and a rectangular plan for a long dining table. Churches have been built cruciform, with all the arms equal, with great domes over the crossing and preaching stages in the centre, while others have been oblong in plan, the congregation facing the eastern end. Thus the plan-shape is partly

determined by practical requirements, partly by personal taste of the designer, and partly by consideration of roofing and supports.

The irregular plan-forms for individual rooms, with which may be included the octagon or circle, present difficulties in linking up with the remaining rectangular compartments of the building, and their shapes may therefore sometimes develop to a rectangle by means of *exedra*, or lobbies (see Fig. 103).

When domed spaces are employed, constructional considerations may dictate the shape of adjoining compartments in order that the main dome may be adequately supported. An outstanding example in which the plan is influenced by the construction of the dome is that of St. Sophia, of Constantinople.

Circular features are valuable when planning on irregular and difficult sites, where they not only permit pleasant plan-forms on awkward

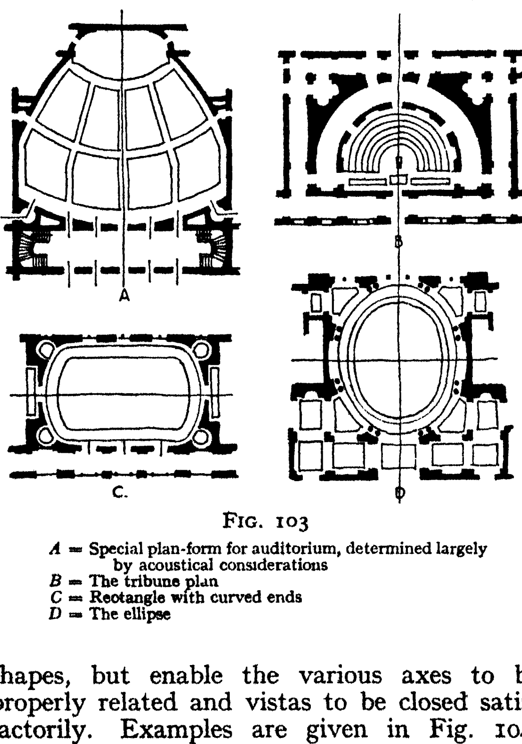


FIG. 103

A = Special plan-form for auditorium, determined largely by acoustical considerations
B = The tribune plan
C = Rectangle with curved ends
D = The ellipse

shapes, but enable the various axes to be properly related and vistas to be closed satisfactorily. Examples are given in Fig. 104, which illustrate the use of the circle and semicircle as turning points for the axes.

The tribune or semi-circular plan-form is frequently employed for council chambers or similar apartments where a small number of persons, such as mayor, clerk to the council, etc., who are of special importance, carry out different functions, and other more numerous people must be accommodated within easy hearing and easy sight of this focal point in the plan. These forms are frequently difficult to handle in planning, and awkward to roof; even more difficult are the fan-shape or conical plan-forms occasionally adopted for modern cinemas, as, for example, The Regent Theatre, Brighton.

Plan-forms may, therefore, be summarized as: square, rectangular, octagonal, circular, elliptical, and variations and combinations of

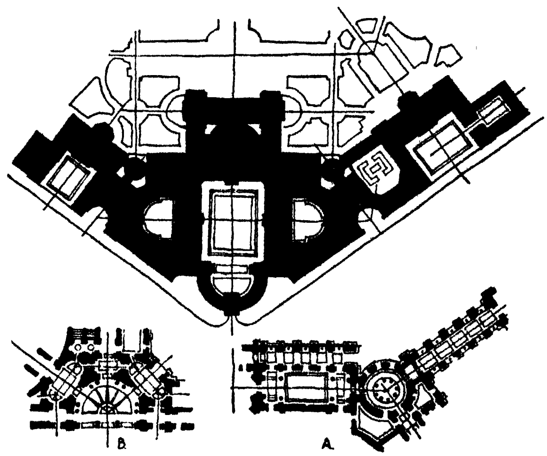


FIG. 104. BLOCK PLAN AND DETAILS OF THE PRIX DE ROME DESIGN BY PASCAL

these simple figures. A few types are illustrated in Figs. 102 and 103.

Services. By this term is meant the small working apartments frequently needed next to large and important rooms; thus the service pantry is an adjunct to the dining room in the domestic building.

Services of all kinds must be carefully adjusted to the work which they are called upon to perform. They must be adequate but not extravagant, centrally placed but not obtrusive, and frequently considerable skill is required to combine these somewhat opposite qualities.

COMMUNICATIONS. This collective term includes porticoes, vestibules, halls, and corridors which connect the various portions of the plan in a horizontal direction, and staircases and elevators which connect the portions of the building in a vertical direction.

Porticoes. Entrances to important public buildings are normally emphasized by the provision of a porch or portico. This feature is partly utilitarian and partly architectural. It must be carefully proportioned to the

programme and carefully related to the exterior. Its scale must be adjusted to the architectural treatment of the façade. It may take the form of a colonnade or arcade, a raised platform, or a mere hood. The *porte-cochère*, or covered portico for vehicles, is sometimes attached to buildings where many persons arrive for special functions.

In cities and towns where street planning does not permit the introduction of a projecting

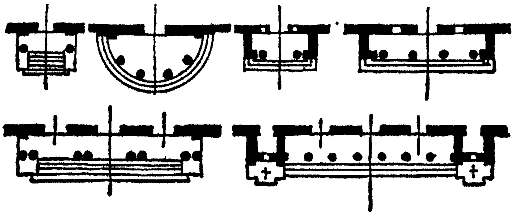


FIG. 105. PORTICOES

portico, shelter is sometimes provided by an iron and glass cantilever roof called a *marquise*.

Vestibules. The vestibule is an important halting place; it is a link between the portico

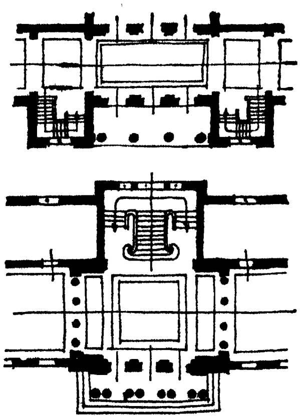


FIG. 106. LOCATION OF THE STAIRCASE ACCORDING TO ITS IMPORTANCE AS A MEANS OF CIRCULATION

and the internal circulation, and, as such, is frequently designed as a compromise between the external and internal treatments. It is usually rectangular in plan, and is sometimes two stories in height.

In some types of building there may be an inner vestibule, which may serve as a lounge or palm court in an hotel, or as the focal point of a minor suite of rooms, such as the foyer to the circle in a theatre, from which the buffet or cloak-rooms relating to that part of the theatre are approached.

Corridors. Corridors may be simple passages about 3 ft. wide, or in important buildings they may assume monumental proportions, as they are frequently used as waiting spaces and assume the status of rooms. In all cases they are of secondary importance to rooms, and must be treated accordingly, but in harmony with the rooms with which they are connected. There may be rooms on one or both sides; the former is the better arrangement as it permits adequate lighting to the corridor, but the latter is more economical, and not objectionable in buildings of one story, in which cast top-lighting to the corridor is possible. The lighting of corridors with rooms on each side may be skilfully managed by means of staircases and borrowed lights, etc. Corridors of great length may be relieved by a treatment in bays, which will, of course, be related to the spacing of the bays of the rooms they serve. The disposition of corridors is a consideration of composition, but it should be noted that since corridors are designed for circulation, they should not lead to a cul-de-sac. Cross-circulation is objectionable but frequently unavoidable. The decoration or paving of the floors of corridors may usefully reflect the importance of the various corridors, and, when necessary, the decoration of the main corridor should be carried through (Fig. 107*C*), while if corridors are of equal importance, the

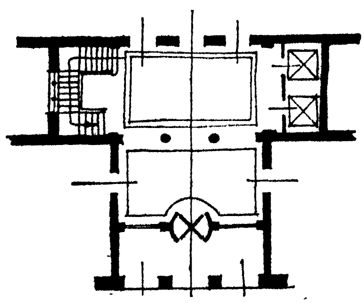


FIG. 106*A*. VESTIBULE OF AN OFFICE BUILDING

junction might be recognized by some special *motif* (Fig. 107*B*).

Staircases. The external staircase is an element in the composition of façades which has been briefly referred to. Internally, it is necessary to distinguish between those for ceremonial purposes, general use, and service. The former usually extend through one story only, and may be located in a staircase hall of fine proportions. A simple straight flight or succession of flights is probably productive of the best results, but even when a change or

return of direction is necessary, simplicity is essential.

Staircases for general use should always be self-contained, and, if extending through a number of floors, should have a landing at each floor level which is distinct from the corridor or lobby to which it gives access, in order to avoid confusion in traffic. The placing of staircases must be related to their importance as a means of circulation. They must always be easily located, and are better placed near to centres of circulation than in an indefinite position on a corridor.

As it is often necessary for the intermediate landing to abut against the external wall, the levels of windows present difficulties in elevation; it is therefore an advantage to place staircases against an unimportant elevation. The practice of permitting the string or landing to cut through a window may sometimes be unavoidable. The dimensions required in specific cases will be referred to later, but in general they will vary from 3 ft. to 6 ft., in which latter width people travelling in opposite directions may pass in comfort. Should the volume of traffic demand greater width of passage, it is better to provide further staircases.

In many types of building the provision of duplicate staircases for use in case of fire is enforced by law. Although external iron staircases have been and are still provided for this purpose, they are not always satisfactory, and in the best practice a concrete staircase is used enclosed by a brick wall, with fire-resisting communication doors from the building proper.

Service staircases are of strictly utilitarian character, and proper location and easy "going" are the chief considerations. In many types of building it is an advantage to anticipate the need for moving furniture from floor to floor, and to design service staircases accordingly.

ELEVATORS. Since these are subject to the same considerations in placing as staircases, they are generally located near them. In most cases it is an advantage to group the elevators together near the entrance, particularly when they are the normal means of circulation. Their size and number will obviously be determined by the estimated volume of traffic during the busiest time of the day; sizes range from about 15 ft. to 40 ft. super for passengers, while those for goods may be considerably larger.

Light Courts and Areas. In buildings extending over a large area it is often necessary to introduce open courts, in order to provide lighting and ventilation to the various rooms. Although often of the smallest dimensions permitted by building regulations, they may become important elements in the composition of the plan, as in the *cortile*, or enclosed courtyard, of the Italian palaces or the Court of Honour of many French chateaux. Apart from considerations of ventilation and lighting, they may be valuable as a means of circulation, and are often the subject of fine architectural treatment.

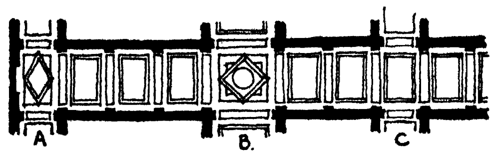


FIG. 107. CORRIDORS

Roofs. The increasing use of flat asphalt roofs makes the serious consideration of the resultant roof from the composition of the plans of most large modern buildings unnecessary. In work of a domestic character, however, the pitched roof is still in general use, and the roofing of complex plans is an important consideration which must be anticipated from the commencement, not only in the avoidance of difficult intersections but in the disposal of rain-water.

COMPOSITION OF THE ELEMENTS

The *programme* must determine the composition of the elements in the plan of every building, and a satisfactory solution of the problem is only found when each unit has been given its proper importance both in size and location.

The principal apartment will be the focal point of the plan, an axiom which applies to every type of building; thus in the lay-out of a municipal building, the council chamber is probably the principal *motif*, and will be the governing factor in the "parti." The theatre should have direct axial approach from foyer to auditorium. The size of these principal features must be exactly adjusted to their purpose. They should neither be unnecessarily sumptuous nor uncomfortably mean. The main hall and approaches must be carefully proportioned to the plan, and to the function which they are called upon to perform, while in large schemes, the general relationship between different blocks of buildings and their relative locations must be considered; thus the plan will be perfectly balanced from every viewpoint. It will lead

from the entrance to the focus, or climax, by direct means. Its adjuncts will be carefully adjusted to increase the importance and convenience of the main features, and these relative proportions will ultimately be reflected in the composition in such a way that the main features of the plan are evident from the elevation of the masses.

Scale, it will be remembered, is largely a question of relative proportions, and it will be necessary to provide proper contrasts between

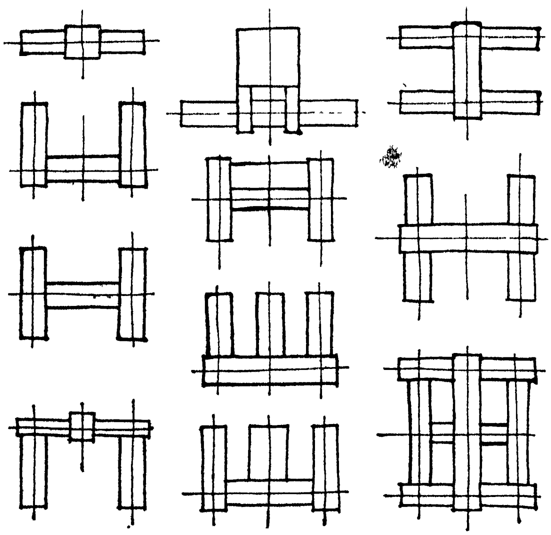


FIG. 108. SIMPLE BLOCK PLANS

the introduction and the climax itself. A high domed space will be the more impressive if approached from a low vestibule, while an interesting decorative scheme will be more telling if it is the culminating feature to a sequence of simple approaches. Variety in shape will be both logical and interesting if the more impressive shapes are reserved for the important rooms, where the stronger contrasts of light and shade, of ornament, or of colour must similarly be applied; but notwithstanding the value of variety in the creation of interest, it must not be overlooked that a similarity or harmony of treatment will create a sense of spaciousness. Harmony is also essential in the design of suites of rooms, for although they may not always be seen together or one from the other, impressions will remain in the mind of spectators.

Axial Planning. It will be evident that the chief artistic desire in planning is the creation of internal vistas, or views, from one room to another, and the closing of vistas with points of interest, and that this results from the arrangement of rooms on a common axis. Such a procedure is highly desirable in monumental work, but must be applied with discretion in domestic and similar small buildings, where the placing of doors in the centre of walls may look well but create undesirable draughts, break up valuable wall space, and result in lack of adequate privacy.

Many of the large country houses of the eighteenth century show the symmetrical plan carried to its utmost limits, the stables, chapel, kitchen, and servants' wings providing minor elements which are balanced on either side of the focal point—the house itself.

Axial planning will at once suggest symmetry, or the balancing of the elements on a main axis, thus producing the sense of equilibrium so pleasing to the artistic emotions. It does not necessarily follow that symmetry demands an absolute similarity in detail of the balancing parts of the plan, but rather that, where logical, the various elements may be grouped together so as to produce similar elevations. Symmetry is only possible when there is an obvious balance of rooms or a sufficiently large number to permit even distribution without dislocation of practical requirements.

Types of Composition. General analysis will show that there are two types of composition —*symmetrical*, and *assymmetrical*, and it has already been pointed out that the first lends itself most readily to considerations of principles. There are many varieties of symmetrical composition, which may be classified as—

1. The simple unit.
2. The closely planned group.
3. The openly planned group.
4. The mass plan.

SIMPLE UNIT. The plan-forms included in this group may range from the small garden pavilion to the vast monuments, such as the Pantheon, Rome. The type of plan will be determined by many of the considerations already enumerated, of which, in structures designed largely for effect, the direction of the axis in relation to the site and approaches is of the greatest importance. The addition of a portico, as a minor element, will often be valuable in that it ties the plan-form with equal axes (such as the square, octagon, or circle) to a definite direction.

GROUP PLANS. Compositions of more than one

unit are naturally governed by the number and nature of the elements to be incorporated, and it is advisable to examine the programme and arrange the required accommodation into as few suites or ranges as possible. This will not

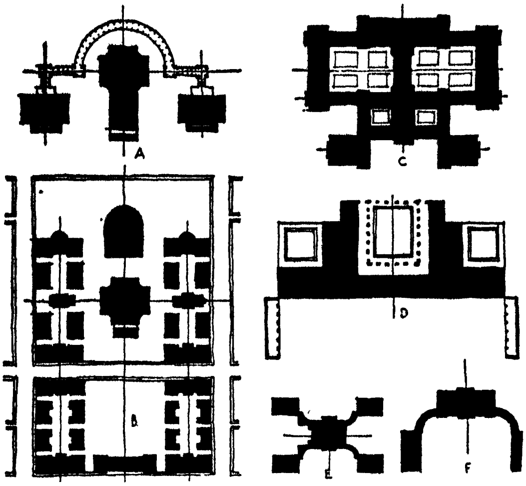


FIG. 109. BLOCK PLANS

A = New York University Library
B = Columbia University
C = Boston Museum (as projected)
D = Pitti Palace, Florence
E = Kedleston Hall
F = Latham Hall

only provide fewer units for composition, but will ensure a simple mass which should produce the best results in elevation. The direction of the axes will be the next consideration. The main axis is invariably central and at right angles to the frontage, but since the focal point, or climax, will usually be the culminating feature on this axis, the general disposition of units will be extended laterally. A variety of block plans is given in Figs. 108 and 109, the study of which will show the manner in which plan-forms may develop in the composition of two or more units.

Reference has already been made to the use of circular forms as turning points on irregular sites.

MASS PLAN. The planning of buildings on restricted town sites is subject to very different considerations, the most important of which is probably the need for the provision of the maximum of accommodation if the building is to be a financial success. Under modern conditions, an ideal arrangement of bays for steel construction frequently provides a more or less rigid basis for the design of the plan, although this in turn is closely related to the more important utilitarian requirements of the

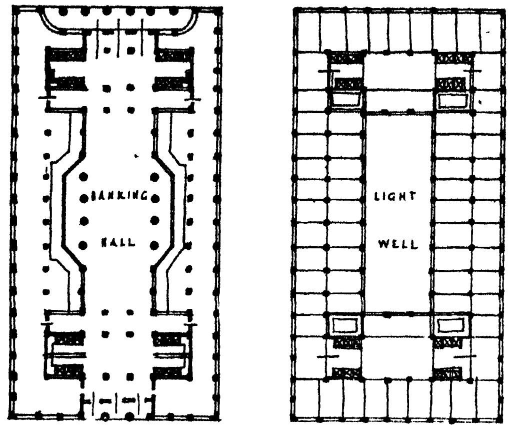


FIG. 110. PRINCIPAL AND TYPICAL UPPER FLOOR PLANS OF AN AMERICAN BANK AND OFFICE BUILDING

programme. An arrangement of set-backs in the superstructure, the provision of wide shop fronts, or the spacing of bedrooms in the upper floors of an hotel, are typical factors which will determine the arrangement of bays on a ground floor. Fig. 110 is an example of this type of plan.

In conclusion, it must be emphasized that besides the artistic and utilitarian considerations involved in planning, a thorough knowledge of construction is essential if a plan is to represent the ideal solution of a problem. Structural difficulties must be present at times, but a sound plan will always offer the simplest tasks in construction which the programme logically permits, thereby reducing costs to a minimum.

Architectural design in its highest and most complete form provides exactly for the requirements of modern civilization translated into buildings. It accurately combines practical requirements and constructional necessities with beautiful expression in such a way that the result can justly be called "fine building." This perfect adjustment of many divergent qualities must be the aim of all who aspire to become accomplished architects.

Chapter VI—HOUSES AND FLATS

Historical. To visualize adequately the requirements of housing, it is desirable that the student should have a brief acquaintance with the conditions of living and the type of house employed in former civilizations. Early civilization originated in the Mediterranean, and as far as research has proved at present it had its birth in Egypt or Mesopotamia ; thus early house planning is associated with a climate of continual sunshine, whereas the modern English house must be suitable for the damp climate of this country. The most complete remains of ancient houses are those of Pompeii, which were probably developed from the Greek plan and were, therefore, typical of the habitations of Greek and Roman civilization. These houses had confined and ill-ventilated sleeping spaces, or cubicles, but pleasant, open courts, and, in some cases, attractive rooms overlooking private gardens. Some of these rooms were of appreciable size, as in the house of Pansa at Pompeii, where the Eocus, or reception room, has approximate dimensions of 38 ft. by 25 ft.

A partial disregard of natural light and ventilation simplified the planning of Roman houses, but these factors, coupled with the dictates of climate, impose rigid conditions on the modern designer.

In England, serious house planning began with the advent of the Norman kings, and early plans indicate the conditions of communal living, which were apparently of widespread application. Thus the castle was the focus of the countryside, the lord was literally the head of a family of people. The conditions of living were very elementary, chimneys were non-existent, and many people slept and ate and lived in the great hall of the castle. These halls were probably extremely uncomfortable, viewed from the modern standpoint. Doors shut into stone walls without frames. The fireplace in the centre of the room must have filled the room with smoke before the smoke finally escaped through a louvre in the roof. Even in later times, when large, open fireplaces came into vogue and chimneys were built, the rooms must often have been at one and the same time suffocating and draughty.

Furniture was mean, and frequently confined to the use of the baron and his family.

In spite of these disadvantages, family life of the Middle Ages was connected much more with the house than that of the families of antiquity, and the development of the house planning of the Middle Ages shows an ever-increasing desire to increase the completeness and convenience of the home.

The walls were of stone and in more important apartments were hung with tapestry. Lavatory accommodation was almost non-existent.

As the house plan developed, the hall was protected from draught coming through the doors by the erection of screens. The portion of the hall occupied by the baron or lord was raised on a dais, and the comfort of his family increased by building a large bay window.

Gradually the communal existence of the baron and his retainers fell into disuse, until the plan of the seventeenth century shows the hall as a mere entrance foyer, which function it has retained until modern times. Real comfort was absent until the Renaissance.

Civilization has led to the subdivision of the uses of rooms, and progress in house planning in England has developed from publicity to privacy by the introduction of doors, corridors, and subdivision according to requirements referred to below. So late as the time of Hogarth (1697–1763) it was the common practice for men and women of fashion to receive visitors into a type of bed-sitting-room. Such apartments frequently appear in Hogarth's drawings.

Published plans of Coleshill (1650) show bedrooms opening from the main hall, or salon, and are probably typical of the fashion of the time.

In important plans from this period until well into the eighteenth century rooms frequently communicated with each other without separate approach by corridors. In Hampton Court Palace as many as seven bedrooms intercommunicate in this way.

Requirements of House Planning. The house, more than any other building, is indivorceably linked up with everyday life. The foregoing review of the development of the

house indicates that changes occurred in planning at the same time that changes occurred in the status and customs of the various classes of the community. This close relationship applies equally to the present day, and the planning of the modern house, whether a humble cottage for a labourer or a large mansion for an owner of more or less unlimited means, must always provide for the individual mode of life. It might even be stated that house design for poorer people may frequently be considered in advance of their ideals and in this way may constitute a valuable form of social education. To appreciate

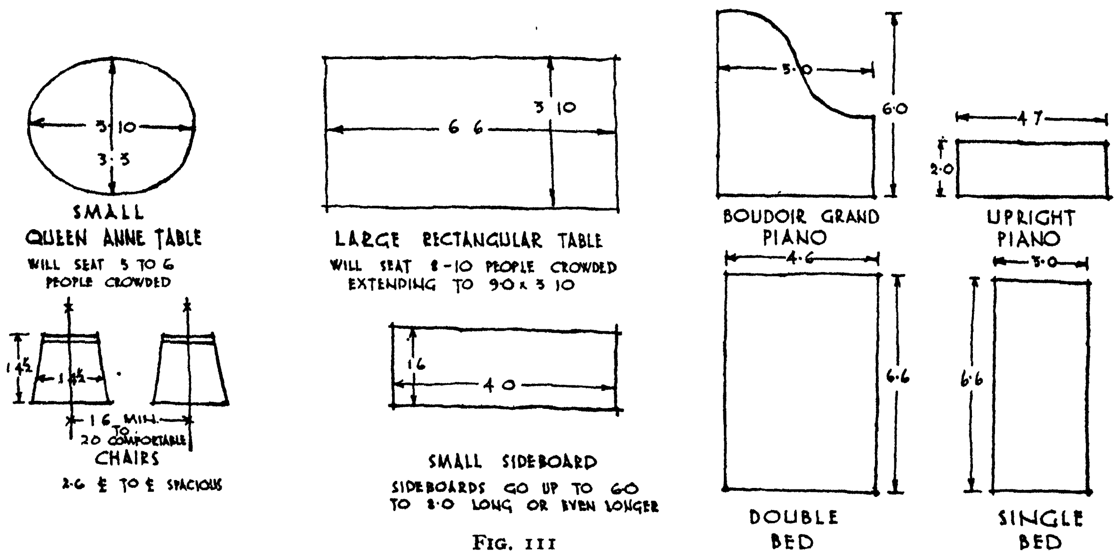


FIG. 111

fully the principles of house planning it is necessary to visualize the requirements of contemporary domestic life. It is important to study carefully the plans of various types of houses and to visualize the placing of furniture; the general routine to be followed in each of the rooms, and between the various suites of rooms; the aspect provided for each main type of room.

In many cases, particularly in the planning of small terrace houses or detached houses on small sites, the possibilities are very limited and the study of existing buildings will show that very few fundamentally different solutions are available. In order therefore, to appreciate the principle of modern house planning, it is necessary to visualize the requirements of modern building. A house may contain some or all of the following—

GROUND FLOOR

1. Entrance hall and/or staircase hall.	6A. Alternatively kitchen and scullery.
2. Cloak-room with lav.	7. Maids' room.
3. Dining-room.	8. Pantry.
4. Drawing-room.	9. Larder.
5. Library or den.	10. Coal or other stores.
6. Kitchen or scullery.	11. Maids' lavatory.

FIRST FLOOR

12. Bedrooms.	15. W.c.'s.
13. Dressing-rooms.	16. Linen cupboard.
14. Bathrooms.	17. Boxroom.

The whole of these rooms should usually be approached either from the hall or from a corridor; each room must normally have a separate means of communication with the rest of the house. Each room must have good window area, must be of a reasonable shape, and provide adequately for the furniture which it is to accommodate. The house will be intersected by a main staircase, and in a large house by a secondary or service staircase.

NUMBER AND SIZE OF ROOMS. The first problem with which the architect is faced in planning a house is a decision as to the number and type of rooms which are to be incorporated in the plan. These will vary with—

1. The social ideas of the client.
2. The area of land available.
3. The aspect of the house.
4. The type of house.

It is sometimes extremely difficult to decide

upon the most suitable type of plan which will embrace the whole of the conditions of the problem.

In the first place, it is of some value to have sizes for standard pieces of furniture. Typical dimensions are shown in Fig. 111.

The arrangement of the more usual rooms will be familiar to students and should be studied carefully, special note being taken of the most suitable positions for doors, fireplaces and windows. The following are points of interest in special cases.

The billiard-room may accommodate a half-size, three-quarter-size, or full-size table, which are respectively 6 ft. by 3 ft., 9 ft. by 4 ft. 6 in., and 12 ft. by 6 ft. The full-size table should have at least 6 ft. clear, unobstructed space on all sides, and half-size and three-quarter-size tables slightly less.

The garage should provide a minimum length for different types of cars as follows—

2 seaters, 10 ft. 6 in. to 12 ft. 6 in.
4 seater, 15 ft.
4 seater Rolls, Daimler, or Sunbeam, 18 ft.

A large car measures 6 ft. to 6 ft. 1 in. over the wings. The garage width should be 7 ft. 6 in. to 10 ft. Height, 8 ft. to 9 ft. 6 in.

The ideal of house planning is to achieve a simple and compact plan which will give the minimum amount of labour and the maximum amount of comfort and convenience. This may necessitate facilities for passing from kitchen to dining-room, either by means of a hatch, a

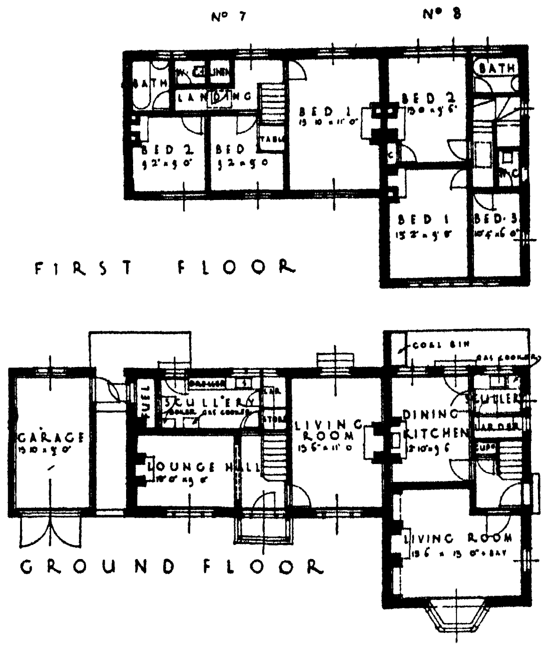


FIG. 112
Architect: C. H. James, F R I.B A, 15 Gower Street, W C

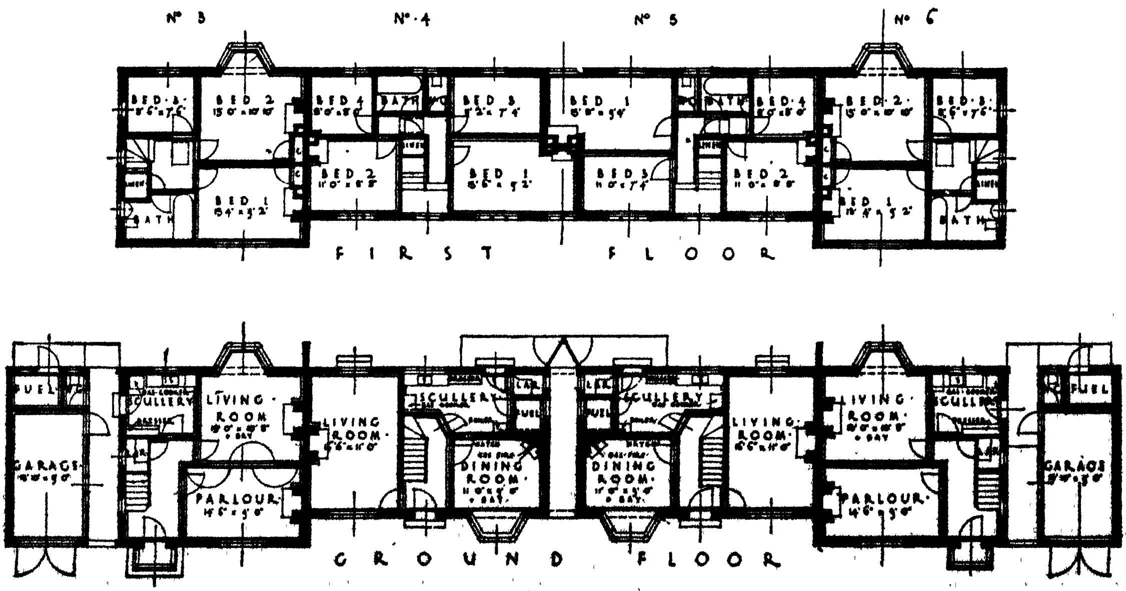


FIG. 113
Architect: C. H. James, F.R.I.B.A., 15 Gower Street, W.C.

special dresser fitting with double doors, or adjacent doorways.

The kitchen may have a north-east aspect and be so planned that the sink and stove are correctly related to each other, and so that daylight and artificial light fall readily on both.

The almost general use of gas and electric cookers makes it less necessary to place the kitchen on the cool side of the house, and if the kitchen is also used as the sitting-room for a maid, it may with advantage have a sunny aspect and pleasant outlook.

The larder should have a north or east aspect, be well ventilated, and be easily accessible from the kitchen, as should also the fuel store and the tradesmen's entrance.

The maid's w.c. should not be placed next to the larder, and the hatch for the delivery of coal should be sufficiently far away to prevent dust finding its way into the larder.

Aspect is of vital importance. Every room should have sun at some portion of the day. The dining-room should face S.E. if it is used as a breakfast-room, so that it will have sun at breakfast and lunch and will be reasonably cool for dinner. The drawing-room should be S.E. to S.W. The best bedroom should face east or south-east.

In some cases there are fine views to be obtained, which must be considered and made available for principal rooms.

Nearly all small modern houses are planned on two floors, and typical plans will give the following accommodation: Small entrance hall, dining-room, living-room, kitchen and scullery combined, larder, fuel store, w.c. If there is room, a small cloak-room should be added. On the first floor there will be three or four bedrooms, a bathroom and a w.c.

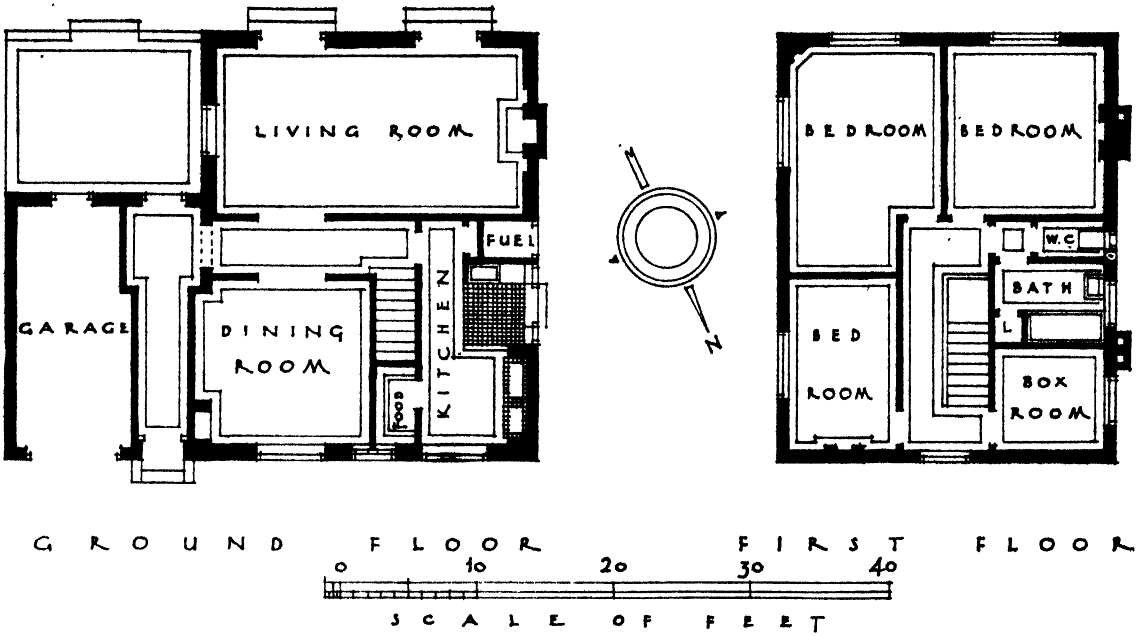


FIG. 114. HOUSE AT FINCHLEY
Thomas E. Scott, F.R.I.B.A., Architect.

The arrangement of these simple requirements calls for considerable skill and understanding of the domestic needs of the occupants. As houses increase in size, the spaciousness of these rooms will normally be the first consideration rather than the provision of additional rooms, but generally such houses are built for clients whose wishes are known to the architect. It is, however, the architect's duty to be aware of the many details and intricacies of house planning and equipment so that he can interpret those wishes and anticipate the many problems of furnishing and housekeeping which the average layman may not be able to appreciate at the planning stage.

Houses may show picturesque or formal

planning, according to the taste of the designer, position of site, aspect, and other considerations.

Small houses are often built in blocks of two, three, four, or six. Terraces are now rarely built except in special circumstances.

The limitations of density, given by recent authorities, are eight per acre in rural districts and twelve per acre in urban districts. These figures have latterly been considered to absorb too much land and to add to transport difficulties, and there is a tendency to adopt a somewhat closer spacing, and in any case they are subject to variations according to circumstances.

Houses of substantial size are usually completely detached. Typical plans of small houses are given in Figs. 112, 113, 114.

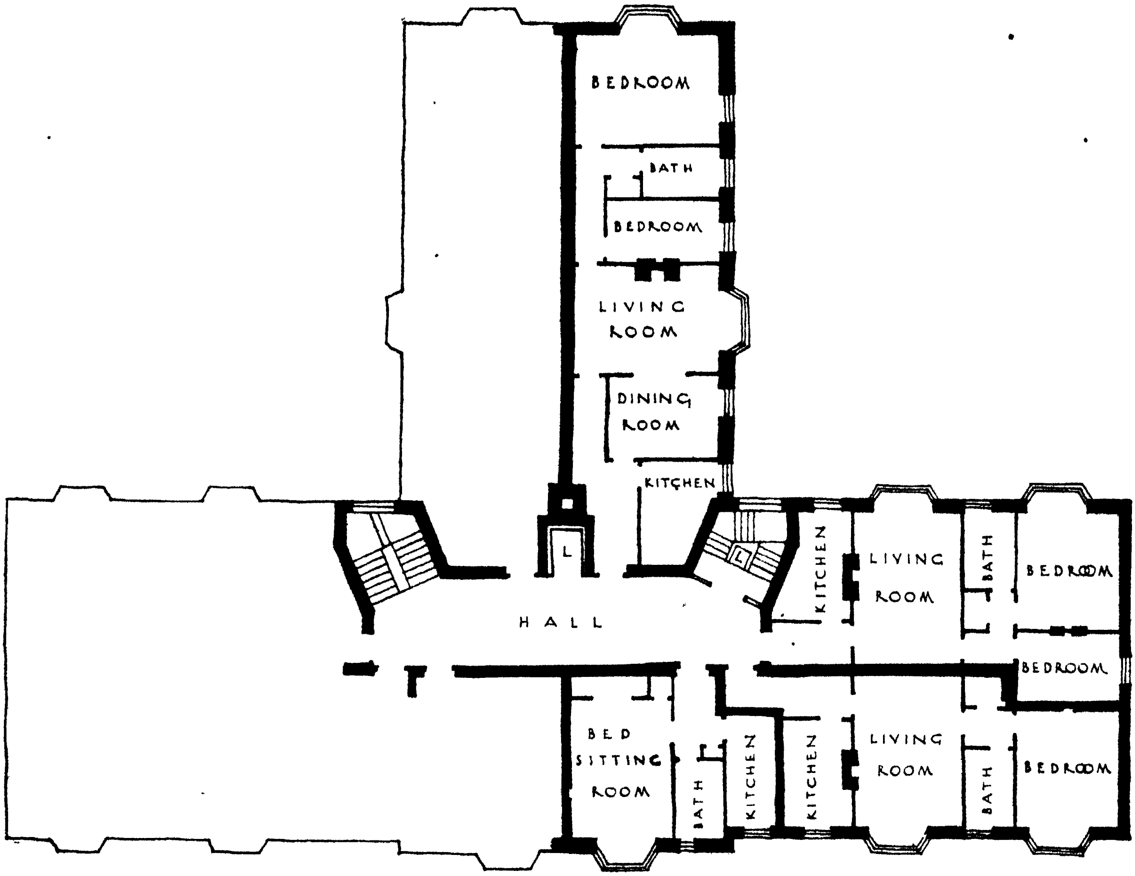


FIG. 115. FLATS AT EALING
Architects, T. P. Bennett & Son, F.R.I.B.A.
First Floor Plan.

FLATS

There are two main types of flats, viz., those which are intended for members of the population who can only be housed adequately by means of state aid, and those flats which are intended to be entirely self-supporting and show a reasonable return as an investment. The former are usually built as two, three, or four storey buildings with the simplest form of service staircase. The accommodation provided is usually similar to that provided in small houses for the working classes. Many interesting buildings have been produced by the London County Council and other local authorities; an interesting continental example is illustrated in Fig. 1. The proposed slum clearance schemes which are to be carried out in many districts offer great possibilities; and the main lines of

one particularly interesting project is illustrated in Fig. 76.

In the second type, the most important considerations are the modes of living of people of the various social grades, and the rentable value of the intended building. These must naturally be carefully considered in the development of a scheme in relation to the value of the site. Flat buildings in which no lift service is available must normally be restricted to a height of four floors, while the provision of a lift will make it possible to increase the height of the building to the limit permitted by building regulations. In many districts the number of flats to the acre is limited under the Town Planning Regulations, and in many of the London suburbs the number of flats is limited to twenty to the acre.

The problem therefore resolves itself into the design of a plan form which provides for the largest possible number of flats with the minimum of staircases and lifts, consistent with good service. Important rooms must have a good outlook and adequate lighting. In many cases it is economically necessary to devote the ground floor and basement to shops and garages and thus secure an increased rentable value.

The flats illustrated in Fig. 115 provide for eight flats of various sizes on each floor and these are served by a passenger lift and staircase, with a separate service staircase and goods lift. It will be noted that tradesmen are required to use the main hall or landing, and to deliver their goods at the front door of each flat. Such an arrangement simplifies planning considerably and is not considered objectionable in flats of a modest rental. The building in Fig. 116 is of a more expensive type, and the number of flats served by each main staircase is limited to two or three on each floor. The larger flats have four bedrooms and two reception rooms, and would naturally command a very high rental. Each flat is also provided with a service staircase, or service lobby and lift communicating direct with the kitchen. In both of these types alternative escapes are provided, and this is normally essential in large blocks of flats. In most cases coal fires are limited to one living room in each flat, the remainder being warmed by central heating and also by electric or gas fires with flues contained in the thickness of the walls. It will be appreciated that the planning and equipment of flats requires expert knowledge of lifts and central heating and hot-water supply. These factors together with other financial considerations must receive adequate attention if a block of flats is to be successful.

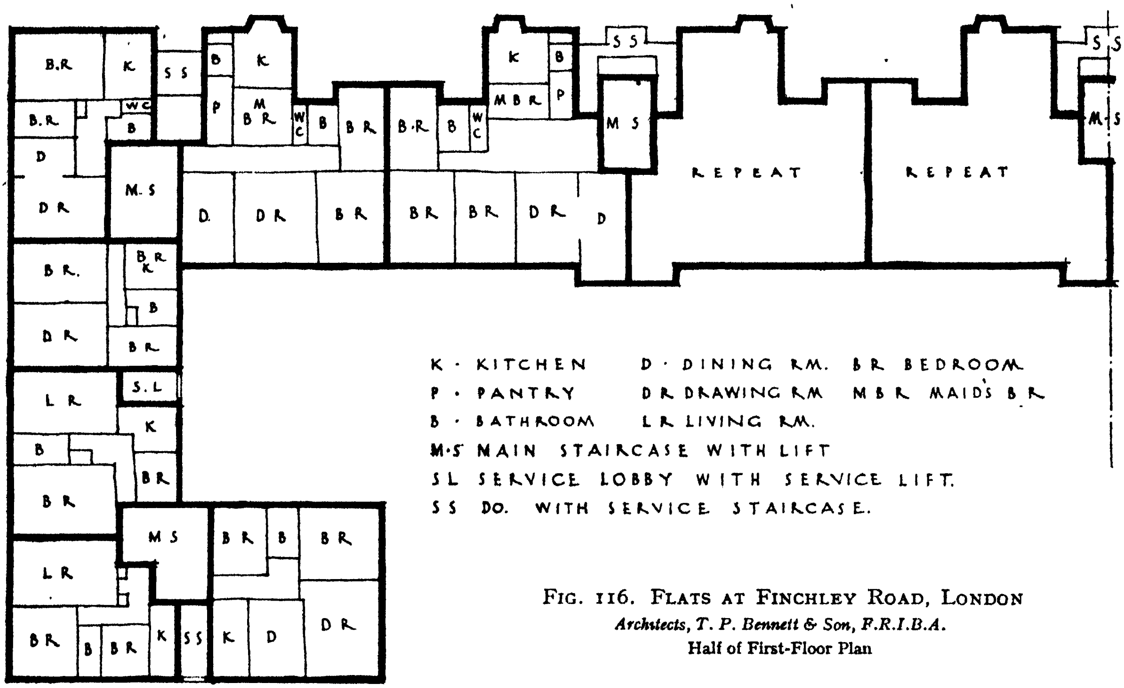


FIG. 116. FLATS AT FINCHLEY ROAD, LONDON

Architects, T. P. Bennett & Son, F.R.I.B.A.

Half of First-Floor Plan

Chapter VII—HOTELS

As hotels have to provide accommodation for very varied classes of people, their requirements are almost as varied as those of houses and flats. The smallest hotels are usually converted private houses, and inasmuch as they are not specially built for their new work, they cannot be regarded as of architectural value. The larger hotels, however, embrace some or all of the following classes—

1. Residential hotels.
2. Private seaside hotels.
3. Commercial hotels.
4. Hotels for the accommodation of well-to-do clients.
5. Accommodation and catering for banquets, weddings, receptions, and other functions.

Residential Hotels. The residential hotel is found in large towns, seaside resorts, and other desirable positions. It must embrace a certain number of public rooms, which must be proportioned to the number of bedrooms. From the purely commercial point of view this apportionment of rooms is one of the most important points, requiring consideration in the laying down of the scheme, and must receive early consideration, but the type of room is also vital and depends upon the kind of client who is to be accommodated.

BEDROOMS. If the amount to be paid per room is small, bedrooms must obviously be numerous. On the other hand, if the clientele is wealthy, there may be a much smaller number of rooms, but in this case they can be large, well-furnished bedrooms or bed-sitting-rooms, or may be grouped in the form of " suites " of varying degrees of importance.

The smallest single bedroom is probably about 12 ft. by 8 ft., and the smallest possible double bedroom about 12 ft. by 10 ft. or 12 ft. by 12 ft., but these sizes must be regarded as just workable dimensions and no more.

For the hôtel de luxe, much larger units will probably be used.

BATHROOMS. The next point of importance is that of bathroom accommodation, which tends to become increasingly prominent, and therefore complicates the planning to a much greater extent than was the case even a few years ago.

In the largest and most expensive hotels, every bedroom will have a bathroom ; and as in England these bathrooms must be ventilated to the open air, they necessitate the use of a considerable amount of external wall or, alternatively, the introduction of a very large number of internal areas. In the cheaper classes of hotels it may be possible to provide as few as one bathroom to 10 bedrooms, and these bathrooms may be economically grouped.

SITTING-ROOMS AND LOUNGES. The sitting-rooms of hotels have undergone a considerable alteration in recent years. The drawing-room is now rarely used and in a new building will hardly be considered a necessity. The lounge, which on occasions may be suitably combined with the entrance hall, is the most important sitting-room.

It should be well furnished, have a good outlook, be free from draughts, and should communicate readily with the main arteries of the building.

If in a residential hotel, it should be given the best aspect and, if possible, the best prospect.

DINING-ROOM. The second room of importance is the dining-room, which must be spacious, well planned, and have convenient access from the lounge and kitchen, the latter by means of a suitable servery or service space. It must be provided with a number of small tables, accommodating from two to six people each ; other arrangements for dining will receive consideration later.

WRITING-ROOM. The next room of importance is the writing-room, and some small accommodation for writing should be set apart even in the simplest of hotels, so that the public accommodation in a small hotel would consist merely of a lounge, dining-room, and writing-room.

Large Hotels. It is impossible, however, to cover all the grades of hotels which may be demanded from the architect, and therefore it will be best to contrast the limited accommodation given above with that of a building of the importance of a central London hotel, where by means of circular revolving doors access is

given to the hotel vestibule from which open the men's and women's cloak-rooms. These may be on the same floor, or may be provided one on the ground floor and one in the basement. This vestibule leads to the lounge, sometimes called the palm court, usually arranged in the centre of the block of buildings so that it may be lit by top light from a large central court, which, above the roof of the lounge, lights the bedroom windows.

The Lounge gives access to the hotel dining-room, restaurant, private dining-room, and smoking-room. In many hotels efforts are made to attract a considerable clientele which patronizes the hotel daily for lunch or dinner, and by means of the private dining-room endeavours to obtain revenue by encouraging private dinner parties, where the guests are able to use the amenities of the lounge and hotel as an asset to entertaining.

The service spaces should have appreciable areas, and should be connected to the restaurant and dining-room by means of one-way doors, and to the kitchen by means of staircases or a battery of service lifts. Special attention must be given to the ventilation of these service spaces so that kitchen smells are cut off from the dining-room.

The folding plates, Figs. 117*a* and 117*b*, illustrate the ground and first floor of the Midland Adelphi Hotel, Liverpool. This building is one of the best of its kind, and illustrates the type of accommodation and circulation that should be provided in a large town hotel. A more recent example is illustrated in Fig. 118. This is a seaside hotel, the planning of which has been dictated by special considerations. The plan is in the form of an arc with the convex side facing the sea. It will be noted that the important public rooms are placed on this side so as to secure the best view, and also that the planning is less formal than is usually the case in a town hotel. The greater freedom in circulation is consistent with holiday life. An elevation of this building is illustrated in the section on History of Architecture, and the main staircase from the lounge in Fig. 59.

STAIRCASES, except where the public rooms are on two floor-levels, have become of relatively secondary importance, and, while they should be spacious and comfortable, do not need to be imposing or to occupy a substantial portion of the plan. They may vary from 3 ft. 6 in. to 6 ft. wide, should be placed in close proximity to the passenger lifts, and, in the case of a large plan, should be well distributed, so that they will provide adequate means of escape in case of fire and give convenient access between floors. Lifts, even in the largest hotels, do not, as a rule, exceed three in number in one place but a high-speed lift properly operated would be sufficient for a large amount of work, and in very many positions one or two lifts are all that is necessary. Service stair-cases must be carefully located, and a lift large enough for furniture is essential in the larger hotels.

Commercial Hotels. In hotels catering for commercial as well as public or family trade, it was formerly the practice to provide separate rooms, commercial travellers being charged at a lower rate than other hotel users. This practice is still very general in hotels in the smaller provincial towns, and public accommodation will then consist of the following—

1. Lounge.
2. Commercial-room.
3. Coffee-room.
4. Writing-room.

The commercial-room is sometimes furnished with a large centre table, with chairs on either side and a large chair at the head of the table, the oldest commercial traveller present being made "chairman." As before stated, this custom tends to disappear as, in common with other conditions of living, there is a universal levelling of social conditions and a general desire to avoid invidious distinction. The modern commercial traveller no longer desires to have his meals in a separate commercial room.

STOCK-ROOMS are, however, still necessary in some form or other. In such rooms, the commercial traveller displays the goods which he has come to sell. In important hotels such rooms are furnished as sitting-rooms, and tables are temporarily placed around the walls or elsewhere upon which goods are spread out. The size of these rooms will vary considerably, but it is impossible to give any adequate rules.

Detailed Planning. Diagram plans are given in Fig. 119 of portions of certain hotels which represent possible arrangements of bedrooms and bathrooms. It should be noted that each suite has a vestibule, a wardrobe cupboard, and a bathroom containing a w.c. In most of the plans the latter is lit and ventilated by a small enclosed shaft. This is unusual in England, where most sanitary

by-laws require every bathroom and w.c. to be lit and ventilated from an open area of at least 100 sq. ft. They further insist upon the provision of a ventilated lobby between the bedroom and the w.c. The bathroom is regarded as a ventilated lobby if the doors are suitably arranged.

It should be noted that rooms of substantial size are shown upon each of the plans illustrated herewith. They are taken from hotels of the highest class where high prices can be charged.

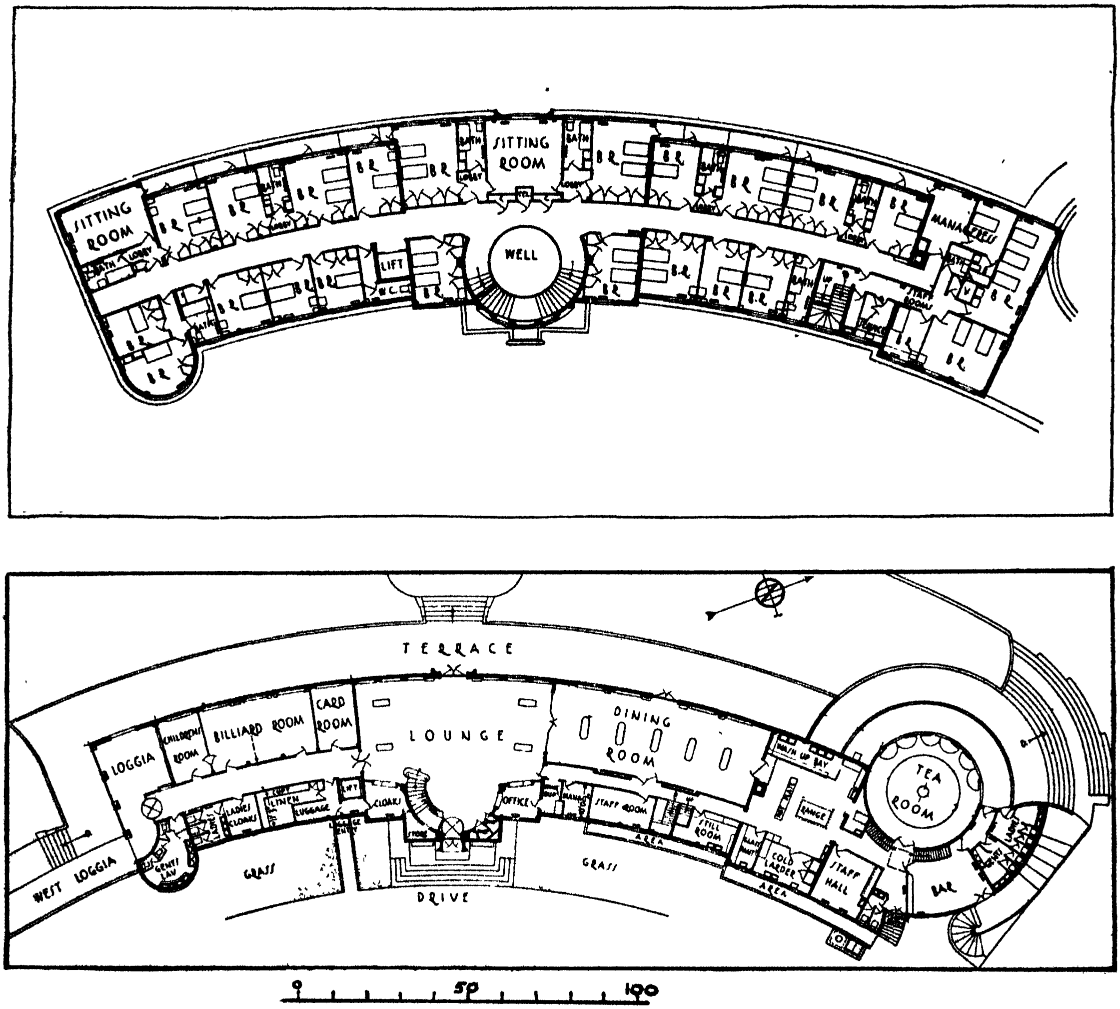


FIG. 118. THE MIDLAND HOTEL, MORECAMBE

Oliver Hill, F.R.I.B.A., Architect.

Upper = First Floor Plan.
Lower = Ground Floor Plan.

Decoration. The decoration of the largest hotels is a matter of very great importance. It is the aim of the designer to present an imposing entrance, and to have decoration of the highest order which at the same time creates a note of originality.

A few years ago, public rooms of big hotels were almost invariably "period" rooms, and a large number are still introduced into modern buildings, but whereas these "period" rooms were limited a few years ago to French treatments of Louis XIV, Louis XV, Louis XVI,

and "Empire," with occasionally an English Georgian room, the range of "periods" now covered is much greater, and there can be Tudor rooms, Italian Renaissance rooms, Chinese rooms, and rooms which are frankly modern, with a tendency to increase the number of purely modern rooms or the original treatment of "period" schemes.

Colour schemes have also received very much greater attention, the colour being considered in conjunction with both building and furniture. Elaborate decorative schemes affect the whole structure, and where they are to be carried out it is advisable to have fairly complete drawings at an early stage of the preparation of working drawings, to avoid subsequent structural alterations, and so that the scheme itself may be as complete as possible.

Financial Aspects of Commercial Buildings. Hotels represent one of the important groups of buildings which are erected primarily as a means of providing substantial return upon capital expended.

It is obvious that very many questions are involved both as to planning, architectural treatment, position, and other factors. In the plan the most vital question is the relation between the number and size of the bedrooms, the number and size of the public rooms, and the class of patron which the hotel aims at attracting.

The hotel with fine public rooms and an insufficient number of bedrooms may be imposing architecturally but doomed financially. Similarly, if a relatively small number of fairly large bedrooms are provided, and the position of the hotel is such that it caters for a patron able to pay only a moderate price per day, the total income would be insufficient to support the staff required to deal with the public rooms. The income from public rooms is frequently augmented by letting portions of them for private dances, dinners, or receptions, but it must be possible to do this in such a way that the interests of the regular patron are not affected.

The right visualization of the type and number of rooms for any particular building is primarily a question for the "hotelier"; but as in very many other instances the architect becomes a greater expert than the client since he will frequently build many more buildings of a particular class than will the individual proprietor. It follows, therefore, that if the architect rightly understands his business, he will be able to offer extremely valuable advice as to the type of room, its size, and the number of rooms to be provided in any particular hotel.

The bedroom is the "key" to the financial success of the hotel organization.

These financial facts, however, enter into many other classes of buildings, and in very many cases there is a similar financial "key"; thus the shop premises depend upon a combination of window and floor space, offices depend upon the combination of letting area and daylight intensity, while banks endeavour to obtain a conspicuous corner site, and theatres rely upon the seating capacity of the auditorium compared with the estimated cost of the type of plays to be produced, standard of scenery, dressing, etc., which is to be adopted.

It is a mistake for the architect to endeavour to ignore this financial side of his work as, while it may not strictly belong to the realm of architecture, it is of vital consequence to a satisfactory solution of the problem presented by the user of the building.

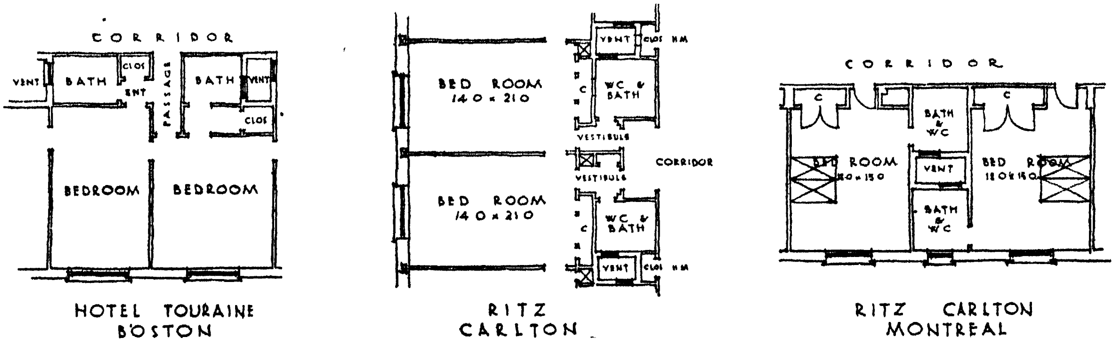


FIG. 119. ARRANGEMENTS OF BEDROOMS AND BATHROOMS

Chapter VIII—SCHOOLS AND SCHOOL BUILDINGS

School buildings have been subject to a very large number of changes in design, and in recent years attention has been focused on their planning and arrangement, not only by educationists and architects, but also by an appreciable part of the medical profession.

The early school buildings were of a very unsatisfactory character, consisting often of one very large open hall without adequate division between the classes.

Teaching was carried on under a system which included one head teacher, or teacher proper, and a series of half-educated teachers, who made pupils recite in unison lessons learned by heart.

This system first began to break down as a result of a more intelligent outlook upon the part of the more enlightened teachers, and in 1872 Professor Roger Smith designed the central-hall school, which has become famous as the Ben Jonson type. This school was condemned because it was thought to involve both a waste of space and a waste of staff, but it subsequently fully justified itself and came into general use about 1904. It was an immense advance upon all previous school types. It separated classes into rooms and arranged for adequate central supervision by means of the central hall, and variations of this type are still erected from time to time.

In 1902, however, the famous Education Act was passed. Among other things, this provided for medical inspection of schools; this supervision aimed at the elimination of epidemics and the reduction of minor ailments, such as colds, etc.

The work of Dr. Leonard Hill, in particular, proved that ventilation was a primary necessity of school planning, and he stated that school buildings must in future provide every scholar with the maximum amount of sunshine and air, and embrace in plan and section a complete system of cross-ventilation. As a result of these demands, many original types of school plan have been evolved. The demand for light and ventilation has given prominence to the desirability of one-story buildings and isolated halls, while low corridors and disconnected lavatory blocks are adopted wherever the general scheme will allow.

School planning is largely governed by the requirements of local educational authorities and of the Board of Education, and certain elaborate rules are laid down which govern the lay-out of school buildings. These rules are, however, subject to modifications to provide for advance in architectural, medical, and educational ideas, and to encourage differences of type and adjustment of planning to site and circumstances. The general rules are as follows:

Site. Secondary Schools. The site should be as open as possible and not adjacent to railways, busy thoroughfares, or other sources of noise. The majority of the classroom windows should face south-east or possibly south. South-west is found to give too much sun in the afternoon and insufficient in the morning, and tends to sleepiness in the summer months.

The exits from the site should not endanger the lives of children from motor traffic, and adequate supervision of the playgrounds is desirable. For each pupil, 50 sq. ft. of playground is required, with a minimum total area of 750 sq. ft.

Surface drainage is required, and loose or dangerous material, such as cinders or gravel, should be avoided.

Playing fields are essential, with a minimum of two acres per 100 students.

Elementary Schools. Similar rules apply for elementary schools. In this case, however, an area of one-quarter acre is required for every 200 pupils to be accommodated, but this may be reduced if the building is of more than one story, or if a roof playground is provided.

For fewer than 200 children 2,000 sq. ft. of playground space must be provided, with an addition of 20 sq. ft. for every senior child and 6 sq. ft. for every infant. For over 200 children, 30 sq. ft. is required per older child, and 16 sq. ft. per younger child. Where provision for playing fields exists, the basic figure given above is altered to 10 sq. ft. and 6 sq. ft. in the first case, and 20 sq. ft. and 16 sq. ft. in the second case.

Entrances. Secondary Schools. Entrances must not lead direct into the assembly hall, and must not be used as a cloakroom. Doors must open outwards. Separate entrances are required

for girls and boys, and in many cases a central or public entrance is desirable.

Staircases. SECONDARY SCHOOLS. There should, as far as possible, be separate staircases for girls and boys, with the necessary provision for alternative means of escape.

Stairs should not be less than 4 ft. wide, with light and ventilation to the external air. Risers must be 5½ in. to 6 in. high, treads 11 in. to 13 in. wide. There should not be more than 14 nor less than three steps in any one flight. Short flights of steps have a tendency to induce the pupils to jump, with consequent disturbance and accident. Steps may be of concrete with carborundum nosing, or hardwood treads on a concrete base.

ELEMENTARY SCHOOLS are subject to similar regulations.

Corridors. SECONDARY SCHOOLS. Corridors should be from 6 ft. to 8 ft. wide and well lighted. Occasionally greater widths are used. Wood blocks or hardwood boards on fillets are probably the most satisfactory flooring materials.

ELEMENTARY SCHOOLS are subject to similar conditions.

Assembly Halls. SECONDARY SCHOOLS. Assembly halls may have an area of 8 sq. ft. per pupil if the number of scholars is 150 or less, and 6 sq. ft. if over 150. Access from assembly halls to classrooms should be arranged without disturbance to other classes. Many assembly halls are now disconnected from all other parts of the building by covered cross-ventilated connecting corridors. Access to the assembly hall for school performances, prize-giving, and other functions should be considered.

ELEMENTARY SCHOOLS. The area required is 3½ sq. ft. per pupil; maximum area, 1,500 sq. ft. Where there are a number of infants or small children, a separate hall or playground is considered necessary.

Classrooms. SECONDARY SCHOOLS. At least four classrooms are required for every 100 pupils, which should contain not more than 30 and not less than 15 scholars. A lecture-room is being regarded increasingly as a necessity. Classrooms are planned with single or dual desks, the floor area in most cases having a minimum of 16 sq. ft. per pupil. Long narrow rooms should be avoided. The height must not be less than 12 ft. if the ceiling is flat, 10 ft. to the wallplate, and 13 ft. to the ceiling if in the roof. The glass area must not be less than a fifth of the floor area. The strongest light should be on the left-hand side of the desks. Skylights can often be made to add substantially to the lighting of the top floors.

It is desirable to provide a platform for the teacher 6 in. or 8 in. above the general floor level.

Experiments in Germany, quoted by Felix Clay, showed the following results in connection with lettering on blackboards—

1 in. letters, scholars tested 81; 76 could read the letters at a distance of 27 ft. 9 in., and 54 could read them at a distance of 46 ft. 3 in.

This suggests that the maximum classroom length should be 35 ft.

Information is given below with regard to the size, area, and accommodation in classrooms of certain German and American schools—

Name of School	No. in Class	Size of Room	Sq. ft. per Head
Boston High School	42	32′ × 28′	21
Professional High School, Pantuchet	49	32′ × 32′	21
Höhere Burgerschule	36	24′ 1½″ × 18′ 4½″	15
New Building, Lessing Gymnasium, Berlin	42	29′ 6½″ × 21′ 4″	13
Sekundärschulehaus, Zurich	42	36′ × 22′ 11½″	20
Madenschulhaus, Zurich	48	37′ × 22′ 11½″	17

Doors should be 3 ft. to 3 ft. 3 in. wide. Walls should be decorated in some shade of buff or cement colour. Artificial lighting of a semi-indirect character gives the best results.

The teacher requires a space of 7 ft. 6 in. wide across the whole of the end of the room, with movable blackboard and desk.

ELEMENTARY SCHOOLS. Area required 10 sq. ft. per pupil; except for those under 7 years of age, where 9 sq. ft. is sufficient.

Younger children require a separate playroom or a classroom having 12 sq. ft. per head. Gangways may be 1 ft. 4 in. in lieu of 1 ft. 6 in. required for secondary schools. Door panels should be glazed to facilitate supervision. Desk space of 20 in. is required for older children, and 18 in. for younger children.

Laboratories. SECONDARY SCHOOLS. In schools having 150 pupils or more over 12 years of age, there must be at least one laboratory; 200 pupils, two laboratories; and 300 pupils, three laboratories.

These should have a floor area of 30 sq. ft.

per head, but this is affected by the spacing of benches, fume cupboards, storage accommodation for specimens, and other fittings.

Benches should be 2 ft. 6 in. by 2 ft. 3 in. for single students, and 3 ft. 6 in. by 4 ft. 3 in. for students working opposite each other. Gangways for single benches must be 3 ft. wide and 4 ft. for students working back to back. Demonstration table and benches must be equipped with gas, water, sinks, and drainage.

In technical schools and advanced laboratories the benches may be furnished in addition with high and low voltage electric current (D.C. or A.C.), compressed air, and hydraulic power.

The provision or otherwise of these services depends entirely upon the character of the work to be carried out.

Botanical laboratories must have a sunny aspect for growing plants. Benches 3 ft. 6 in. by 2 ft. 6 in. per pupil should be provided. Glasshouse accommodation is also necessary.

Laboratories should be grouped as far as possible in one part of the building, so that they can all be under the control of a science master or the head of a science department, and so that drainage and supply services may be facilitated and made as economical as possible.

Benches should be of pitch pine or teak, according to the amount of money available.

ELEMENTARY SCHOOLS. Science rooms are occasionally provided with small benches and fittings, and should have an area of 20 to 25 sq. ft. per head; otherwise they follow the regulations for secondary and technical schools in a modified form.

Art Rooms. SECONDARY SCHOOLS. Art rooms require north lighting and an area of 30 sq. ft. per pupil. There should be separate studios for elementary and advanced work; and in the case of a technical school, separate studios for design and drawing from the cast, and, if necessary, separate life rooms.

In design rooms, students usually work on desks. In antique studios, they work on easels, and must be able to place an easel in a satisfactory position as well as to move the easel into any required light.

In life studios, the model must be centrally placed and the students arranged in a semicircle facing the model. Powerful artificial light is required on the model, so that false effects and difficult drawing do not arise as a result of light reaching the model from many small sources of light. The artificial lighting of life studios is a difficult matter and must be carefully considered in each case, if possible in conjunction with the principal art master.

ELEMENTARY SCHOOLS. Similar rules to those of secondary schools apply, modified as necessary to suit the number of students who will use them regularly.

Housecraft Room. SECONDARY SCHOOLS. There is an increasing demand for the teaching of domestic subjects in secondary and technical schools, and accommodation in these cases will be provided for housewifery, cooking, and laundry.

In cooking and laundry schools, there should be an allowance of 30 sq. ft. of floor space per student, with an allowance of 5 sq. ft. per head for fixed apparatus. The class should not exceed 20 in number. North light is desirable. The arrangement of the benches or tables and of the teacher's desk is subject to considerable variation, according to the views of the teacher and the demands of the particular school or locality. The benches sometimes face entirely in one direction, and are sometimes arranged in the form of a hollow square, the pupils working on the outside. Special attention should be given in cookery schools to the provision of gas and coal and electric cooking ranges.

Housewifery is best taught by the provision of a small completely equipped flat, but this is only possible in the case of the largest school centres.

Preparatory and Kindergarten. SECONDARY AND ELEMENTARY SCHOOLS. Special provision is being increasingly made for the teaching of small children under open-air conditions; and even where rooms are provided in completely enclosed buildings, additional light and air is usually secured for the kindergarten rooms, as is also S., S.E., or S.W. aspect, while large open fireplaces are usually considered desirable for the winter.

Staff rooms, stores, and service rooms are provided according to the demand of the school. A music practice room, where provided in secondary schools, should be 8 ft. by 8 ft. 6 in. with sound-proof partitions.

Gymnasiums. SECONDARY SCHOOLS. Where provided, these should be 50 ft. by 25 ft. or 60 ft. by 30 ft., with a minimum height of 16 ft. Window sills should be 9 ft. from the floor to provide ample space on the wall for fixed apparatus.

Cloakrooms. SECONDARY SCHOOLS. Separate cloakrooms for each sex are necessary, and should be as near the entrance as possible.

They should be well lighted and well ventilated. Pegs for boys should be 10 in. apart in one horizontal row, and for girls 15 in. apart. A space of 5 ft. is required between the stands. Pegs may be placed in two rows zigzag without difficulty.

Cloakrooms are often provided with bostwick gates, so that the maximum amount of air circulation is secured.

Lavatories and w.c.'s. SECONDARY SCHOOLS. Lavatories must be provided in the following proportions—

BOYS.

1 basin for every 20 boys up to 100.
1 basin for each succeeding 25.
18 in. allowed per basin.

GIRLS.

1 basin for every 10 girls up to 100.
1 basin for each succeeding 20.
18 in. allowed per basin.

A lock-up slop sink and basin should be provided for the use of the caretaker.

Closets are required as follows—

BOYS.

1 closet for every 25 boys.
These must be disconnected from the main building.

GIRLS.

1 closet for every 15 girls up to 100.
1 closet for each succeeding 20.
These should be in the main building but suitably isolated or approached by a covered corridor.

Urinals for boys in the following proportion—

1 for every 15 up to 100; and
1 for each succeeding 20.

Generally, closets should not be wider than 3 ft. nor less than 2 ft. 3 in., each lighted and ventilated and having a door which should be 3 in. short at the bottom and 6 in. short at the top.

Partitions are best when carried up for 6 ft. only, and should be constructed of some hard smooth material on which writing is impossible. Each w.c. must have a separate flushing cistern.

ELEMENTARY SCHOOLS. Basins are required at the rate of one for every 25 pupils. The regulations for closets are similar to those for secondary schools, but the number required are as shown in the next column.

In blocks of offices common to infants of both sexes there must be urinals which, with closets, must be partitioned off from the younger girls' w.c.'s.

If the number of infants is small, blocks may be common to older girls and infants, but a

Number of Children	Girls	Boys (in Addition to Urinals)
Under 30 . . .	3	1
" 50 . . .	4	2
" 70 . . .	5	2
" 100 . . .	6	3
" 150 . . .	8	3
" 200 . . .	10	4
" 300 . . .	14	5
" 400 . . .	18	6

proper proportion must be made suitable for children under 8 years of age.

Earth closets of approved type may be used in country districts, but drains for slop and surface water will still be necessary.

Urinals must be separate from closets and should provide 10 ft. run per 100 boys.

General Planning. The building illustrated in Fig. 120 may be looked upon as one of the best examples of modern school planning. It has been designed as a technical college, providing both general education and technical instruction for those entering the building and engineering industries. The classrooms generally are placed on the east and south elevations while drawing offices and art rooms have a north light. The building is planned on a unit basis, and constructed as a steel-frame building. For the most part the stanchions are about 10 ft. centre to centre, and the classrooms are about 24 ft. wide with corridors 8 ft. in width. It will be noted that the gymnasium has been detached so as to provide complete cross ventilation and also that the workshops are similarly detached, thereby concentrating all of the rooms where noisy operations are carried on and isolating them from the rest of the building. The elevation of this building is given in Fig. 94, from which it will be seen that the maximum possible amount of side lighting is provided to all important rooms, and thus full use is made of the possibilities of steel-frame construction.

ELEVATIONS. The elevations of school buildings require careful handling in order that the building itself may appear attractive without involving excessive cost. Recently considerable efforts have been made to reflect the material of the locality in the design; and in those instances in which the district or neighbourhood has some special connection with a famous man, paintings or references to this man have sometimes been used as the keynote of the interior treatment.

Owing to the rapid changes in the views of leading educationists, some school architects have suggested the increased use of buildings of a semi-permanent character, so that any future modifications of planning or design could be dealt with satisfactorily. Such semi-permanent construction requires some considerable skill in handling to prevent its costing almost as much as a permanent building without the advantages which first-class construction gives.

To summarize the advice given in this treatise on Architectural Design, studies must be devoted to—

1. The theory, details, and materials of construction.
2. The practical requirements of buildings.
3. The principles of good design.

Students should make themselves conversant with the fundamental requirements and characteristics of each important type of building, and they should study contemporary architecture as plans and other details are published in technical periodicals. This study may be undertaken from three points of view, firstly, *the technical processes and customs*; secondly, *actual details of planning*; and thirdly, *the regulations governing each type of building*. This information might appropriately be made in the form of research sheets, which should be carefully filed, together with such illustrations as are available.

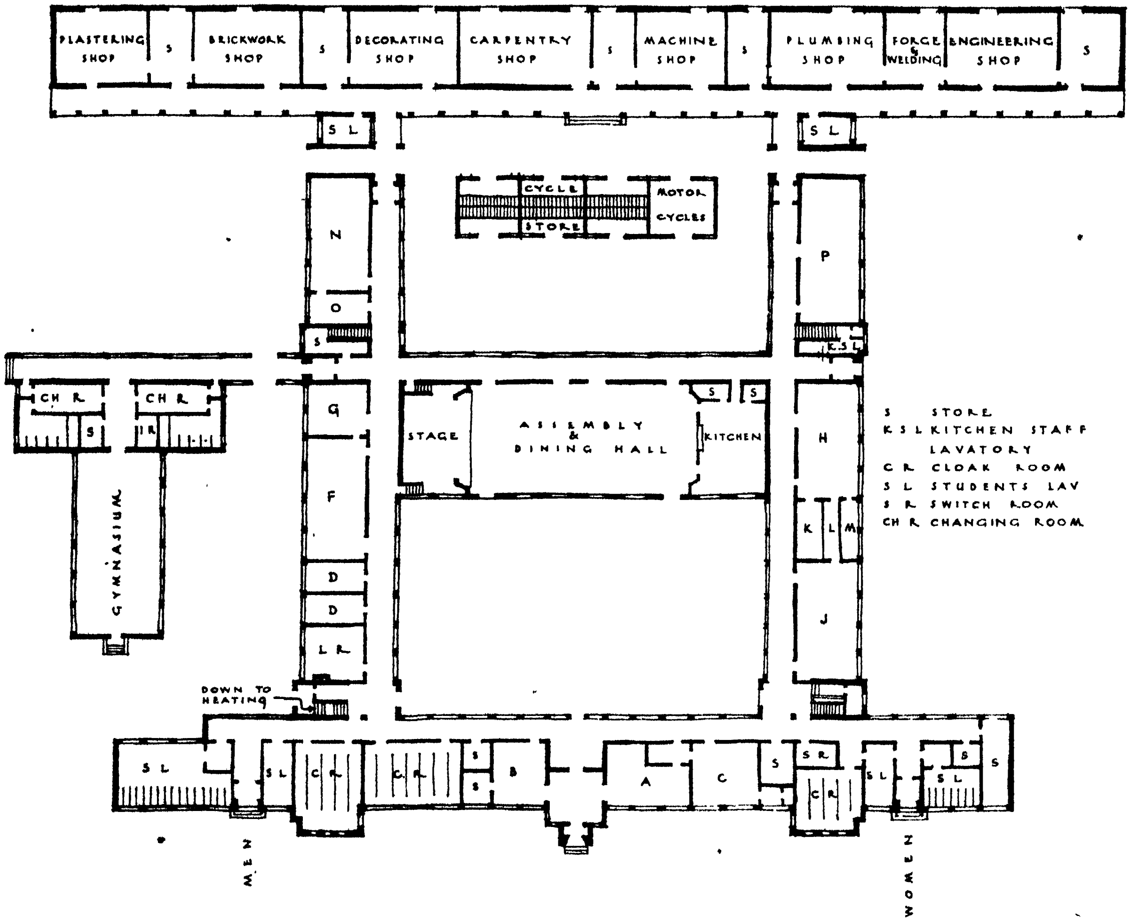


FIG. 120. TECHNICAL COLLEGE, NEASDEN, FOR THE MIDDLESEX COUNTY COUNCIL

W. T. Curtis, F.R.I.B.A., County Architect.

Ground Floor Plan.

Architectural Acoustics

By A. G. Huntley, A.M.I.Struct.E.

Although by usage the term Architectural Acoustics is generally employed in a proscribed sense to cover only those problems relating to the propagation of sound waves in auditoria, it does in its widest sense include all aspects of sound in buildings, e.g. the transmission of internal noise; the intrusion of external noise; and the control of vibrational noise, as well as the propagation of sound in auditoria.

Consider first, the question of propagation of sound in auditoria. The problem was appreciated centuries ago and there are both ancient Greek and Latin writings on the subject, yet it is only within the last fifty years that investigations have been sufficiently determined to result in the science of architectural acoustics being lifted from the haze of doubt and uncertainty, and placed on a sound and sure basis. Now, however, the problem, even before a building is erected, can be solved like any other building problem, such as ventilation, and provision made to ensure that on completion the structure shall be really capable of absolutely fulfilling its purpose.

Fundamental Principles

Before considering our problem proper, it is necessary fully to realize and appreciate the fundamental principles common to all sound problems. In the first place, sound is a form of energy and, as energy is indestructible, the process of creating and dispersing sound is one of transforming some kind of energy, usually mechanical, into sound energy, and then resolving that into a different type of energy again, usually heat. For example, the mechanical energy of an electric motor is converted into sound energy by the action of bellows, driven by the motor, operating an organ pipe. The sound energy thus produced continues until, in its turn, it is transformed into heat energy by the friction between the sound waves and the surfaces with which they come into contact.

Sound Waves. Sound is transmitted through the atmosphere in the form of *waves*. As an analogy, take the way waves travel over the surface of the water in a pond when, say, a stone is dropped into it. The energy possessed by the falling stone creates a ripple on the surface of the water which, spreading in a circle from the source, eventually passes over the whole surface of the pond. Now, supposing we have a series of stones of the same weight successively dropped from the same height into the pond, we should get a series of similar waves rippling in succession over the surface of the water; but, if the weights of the stones vary, then the energy of the stones striking the water will vary and, consequently, larger or smaller waves will result.

It is the same with sound waves, with the exception that, as the medium through which they travel, namely the air, entirely surrounds the source producing the initial impulse, they naturally spread spherically through it and, just as the varying energy of the dropping stones produced various sizes of waves, so varying initial impulses produce different sizes of sound waves. The greater the impulse, the larger the wave.

Now, suppose we have two organ pipes, one treble, the other bass, and suppose they each emit a continuous note, more energy will be required for the bass, it being a very much larger pipe, than for the treble; the bass, therefore, produces a very much larger wave, but as the speed of sound is constant, 1,100 ft. per second in round figures, it follows that the smaller wave must have more vibrations per second than the larger one, as it has to maintain the same speed.

To illustrate this: once upon a time, Mr. Python was going for a walk, or rather a wriggle, when he chanced to meet Mr. Viper. After passing the time of day, they decided to continue their walk together. Mr. Python set off by wriggling his body in large, slow undulations, while Mr. Viper had to wriggle his tiny body very quickly indeed in order to keep up with him, and so produced a large number of small, quick undulations. They were thus both travelling at the same speed, but Mr. Viper had many more wriggles to the second than Mr. Python.

This rate of vibration, or *frequency*, as it is termed, is used as the standard means of identifying sound.

For our purpose, we shall deal with octaves only, denoting the compass by the letter "C," and the pitch at octave intervals by "C" with the suffixed figures 1 to 7, together with each note's rate of vibration, thus –

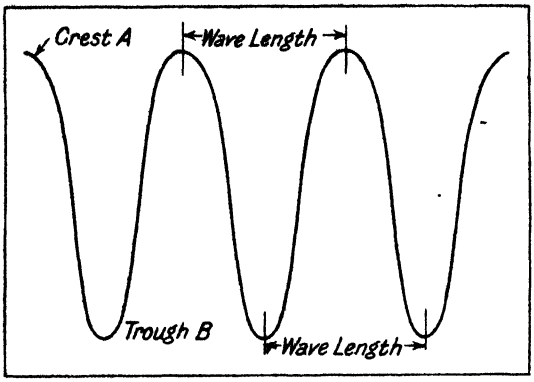


FIG. 1. THE SOUND WAVE, DIAGRAMMATICAL REPRESENTATION

C_1 64, C_2 128, C_3 256 (middle "C"), C_4 512, C_5 1,024, C_6 2,048, C_7 4,096.

From these figures it will be seen that, as the sound rises, each octave has double the number of vibrations per second of the octave immediately below it.

Further investigation into the character of the sound wave will bring the following terms into use—

1. Condensation,
2. Rarefaction,
3. Wavelength;

and they will be definitely explained before proceeding farther.

As will be seen from Fig. 1, the sound wave is made up of a crest *A* and a trough *B*. That is, we first of all get a wave of condensation forming the crest, and this is followed by a wave of rarefaction forming the trough. For an illustration, imagine a punch-ball, suspended from ceiling to floor, receiving a sharp, horizontal blow. The ball, moving under the force of the blow, compresses, so to speak, the air in front of it (condensation), at the same time leaving a partial vacuum behind it (rarefaction).

Wavelength is defined as the distance between crest and crest, or trough and trough; thus it will be seen that the length of the wave varies according to the pitch. The higher the pitch, the shorter the wavelength.

$$\text{Thus wavelength} = \frac{\text{Speed}}{\text{Frequency}}$$

So much for the general terms relative to our subject. Now for the particular ones, namely—

1. Reverberation.
2. Absorption.
3. Resonance.

Reverberation. We have already seen that energy, having been expended in producing sound, must continue as sound energy until it is transformed into some other kind of energy, which transformation is brought about usually by friction between the wave and the air and surfaces with which it comes into contact. Obviously, the more friction produced, the quicker will the transformation be effected. This transformation is a gradual process, and so must operate over a certain space of time. This space of time is termed *reverberation*, the text-book definition of which is as follows—

> The time taken by a constant sound of average intensity to die away past the threshold of audibility after the source creating it has been stopped. In this definition, a constant sound is taken to mean a sound sustained for sufficient time to allow of its completely filling the whole volume, while average intensity is 1,000,000 times the threshold of audibility.

As an example, suppose an organ pipe is sounded in an empty hall, and then suddenly stopped by the cutting off of the air supply, the sound which it emitted will be audible over a space of some seconds afterwards, loud at first, then gradually dying away. In other words, there is a period during which the sound decays from a maximum to nothing, and it is this period of decay to which the term "reverberation" is applied. The time of reverberation may vary from nothing in the open air to 10 to 15 seconds in empty buildings.

Absorption. When a sound wave strikes a surface, part of its energy is absorbed by friction, part is transmitted, and the remainder is reflected. For just as a mirror reflects light, so all surfaces reflect sound, and very often they reflect a higher percentage of the sound than a good mirror does of light—glass actually reflecting about 98 per cent of the incident sound. But it is this loss by friction with which we are most concerned, because, as already shown, reverberation is directly dependent upon it. This property of being able to transform sound energy is termed *absorption*, and the degree to which various materials are able to cause it, is termed their *coefficient of absorption*. As would

be expected, porous materials have a higher coefficient of absorption than hard, dense ones, because, naturally, more friction is induced as the sound waves penetrate into the interstices of the material. Table I, compiled by Professor W. C. Sabine and others, gives the coefficients of absorption for a certain number of building materials in *open window units*.

These coefficients are reckoned in comparison with an open window, because an open window is taken to be entirely absorbent, for a sound wave reaching an open window must pass completely through it.

TABLE I

COEFFICIENTS OF ABSORPTION AT 500 CYCLES

Materials, etc.	Units per Sq. Ft.
Open window	1·00
Audience (per person)	4·00
Brick or tile wall, smooth lime plaster finish	0·25
Lath and plaster (lime)	0·03
Lath and plaster (rough finish)	0·04
Glass	0·027
Wood floors or panelling (unvarnished)	0·06
Wood floors or panelling (varnished)	0·03
Linoleum	0·03
Carpets or felt	0·25
Curtains (heavy)	0·3
Curtains (light)	0·1
½ in. fibre boards (undistempered)	0·25
Special Absorbents—	
Acoustic plaster, ½ in. thick	0·30
May acoustic cementitious tiles	0·40
Acousti-Celotex, 1 in.	0·70
Spray asbestos, 1 in.	0·70
Cabot's quilt, 1½ in. thick, with fabric cover	0·6
Glass silk or slag wool, 2 in. thick	0·85
Bentwood chairs	0·2
Cinema seats, plush	2·6
Cinema seats, leather	1·6

These coefficients are for the pitch middle C (C_3256), and have been calculated in the following way. A simple building was taken, having a hole of given area in one wall. A standard source of sound was operated in it, and the period of reverberation, or decay, measured. The hole was then completely filled and the material under test brought into the room. It was then quite a simple matter to measure the area of the material under test that was required to be introduced, in order to produce the same reverberation as that ruling before the hole was blocked up. In this way a direct comparison was obtained.

Resonance. This is, unfortunately, a term which is continually very loosely used. It has, however, a very precise and definite meaning, and is applied, in scientific literature, to the phenomenon, wherever it may occur, of the growth of vibratory motion in an elastic body under periodic forces timed to its natural rates of vibration.

As an illustration of this, take a large bowl of water and strike the surface of the water in the centre with the palm of the hand. This will cause a wave to spread, which, reflected at the edge of the water, will return to the hand. If, just as the wave reaches it, the hand again strikes the water, it will reinforce the wave, which going out stronger than before, returns again. It is evident that if this process is repeated a considerable wave can in time be created, so that if the interval of time between crest and crest, that is, the frequency of a particular sound wave, happens to correspond with the natural rate of vibration in, say, a particular piece of wood panelling, the panelling will, by resonance, increase the energy of the wave on reflection. It, therefore, follows that resonance will alter the total amount of sound energy in a room, and will always increase it at its particular resonating frequency.

From the foregoing it will thus be apparent that resonance is an important factor; but the difficulty is that a body is only resonant under those forces timed to its natural rate of vibration, and therefore, as far as sound is concerned, will only reinforce certain tones of a complex sound, and consequently will exert an unbalancing and distorting effect. This action of resonance may also be caused by the air enclosed in a room, so that every room has a definite pitch to which it responds; the smaller its volume, the higher the pitch. Of resonating material used in building construction, wood is the most important, as, of course, it usually occurs in large areas, e.g. floors and panelling, etc. As its coefficient of absorption is double that of ordinary plaster, its use as an interior finishing is of considerable value as an absorbent, also its general reinforcing effect, due to its resonance, very much outweighs any disadvantage that may be produced by distortion. As an example, it is particularly useful in the construction of platforms.

For platform construction, whether for speech or music, it has been found from practical experience that considerable reinforcement of sound can be obtained if the floor of the platform

is of wood carried on at least 6 in. joists, thus providing a 6 in. air space below the floor. Also when panelling is used at the back, and at the front between the platform and the main floor, it should be fixed as positively as possible both to the platform, and, in the latter case, to the main floor as well (see Fig. 2).

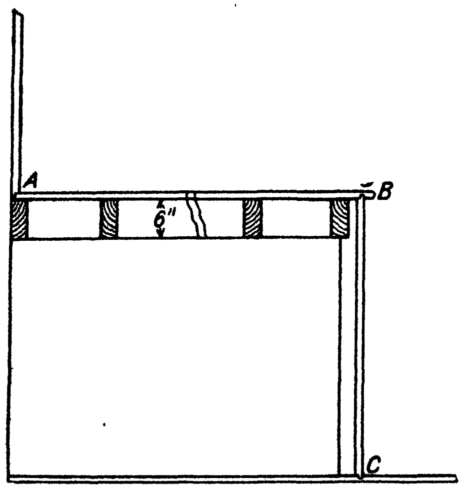


FIG. 2. DIAGRAMMATICAL PLATFORM CONSTRUCTION, SHOWING POSITIVE CONNECTIONS AT *A*, *B*, AND *C*

Large areas of plaster, particularly on metal lathing, may also produce resonating effects.

CONDITIONS FOR GOOD ACOUSTICS

The conditions which will obtain in an auditorium possessing good acoustic properties may be divided into four headings—

1. The initial sound should possess adequate loudness.
2. It should be evenly distributed over the whole area taken up by the audience.
3. It should be clear and distinct.
4. It should reach the auditors in the same pitch and tone as it was produced.

Adequate Loudness. The first condition is, more or less, self-explanatory; we must have sufficient sound energy to fill our building. It would, for example, be no use expecting a speaker, unaided by mechanical means, to make himself heard all over the Wembley Stadium, or in Olympia. Mechanical means is here taken to imply loud speakers and other electrical devices; structurally, however, we can do a good deal to ensure adequate loudness over as large an area as possible.

First, let us take the simplest case, that is, that of an orator standing on a flat and level plain, and follow the improvements that can be effected step by step. We find that the sound spreads out all round him in an ever-increasing sphere; as it spreads, the intensity of the sound energy at any point on the circumference rapidly decreases—decreases, in fact, at the rate of the inverse square of the distance from the point of origin, from which it is obvious that the effective range of a speaker in the open air is very limited. Now, to improve matters, the speaker can be raised up on a platform, which will allow a larger portion of the wave sphere to cover a greater area of auditors; and, again, if we raise the auditors, tier by tier, a still greater area of sound sphere must be usefully employed.

To understand these steps fully, we must remember the manner in which sound energy was dissipated by absorption, for, with the source of sound on the ground, the auditors immediately surrounding it quickly absorb the energy of that part of the wave sphere which strikes them; the remainder passes on over their heads and is lost. When, in turn, the speaker and the audience are raised, as already pointed out, a large portion of the sound wave is usefully employed, and consequently the effective range of the speaker is greatly increased.

The last steps that can be taken to aid open-air speaking are to have the audience in a semicircle, and to place a hard surface behind

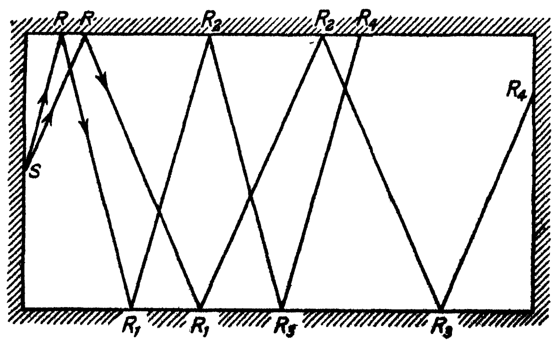


FIG. 3. PLAN OF BUILDING

the speaker to reflect over the audience the sound which would otherwise be lost behind him. This last course is rendered expedient because, apart from the natural objection of looking at a man's back, sound, emerging from the mouth, cannot spread in a true sphere because of the interference produced by the head, which naturally creates a zone of partial silence behind. And now we have, roughly, the

shepe and construction of an ancient Greek theatre.

Proceeding, it becomes obvious that, sooner or later, a roof must be added to the structure, and it is here that our troubles begin, for the wave that previously passed over the audience's heads and was lost is now retained and, striking the roof, is reflected back to the audience, which is most desirable, provided it can be controlled,

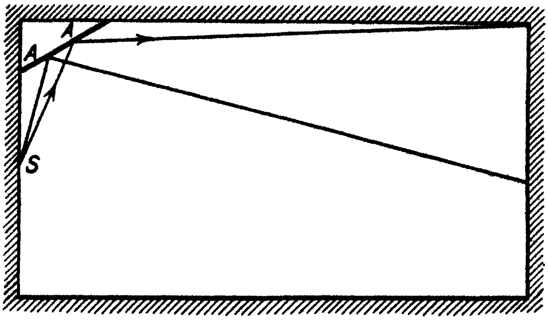


FIG. 4. ALTERNATIVE PLAN

as the provision of adequate loudness over a much greater area can be secured by proper use of these reflections.

The difficulty lies in the controlling, for the second condition lays down that the sound must be evenly distributed; it is of no use getting this reflected sound in concentrated patches, as other areas will then not get their fair share of the additional energy.

In determining the effect produced by various reflecting surfaces, a pencil ray, or small beam of sound, is only considered, and reflections are taken to follow the same laws as reflections of light, that is, the angle of incidence equals the angle of reflection, diffraction being ignored.

Even Distribution. In dealing with the problem of even distribution, we must remember that the sound wave is made up of a wave of condensation and a wave of rarefaction; and now, supposing we follow the paths of two pencil rays, we may find that after being reflected from different walls, or, perhaps, the ceiling, their respective paths will cross each other. If these paths have been exactly the same length, the wave of condensation of one will arrive at the same time as the wave of condensation of the other, and, therefore, at that point there must be mutual *reinforcement*. But it might equally well happen that their paths, being of different lengths, the wave of condensation of one would arrive with the wave of rarefaction of the other, producing *neutralization*, thus setting up a zone of comparative quiet. Or, again, one ray might have a very long path, and the other a very short one, so that the first would arrive at an appreciable time after the other had passed; then we should get conditions tending to produce an *echo* at that point.

From the foregoing, it would seem that to provide for even distribution of the sound is almost an impossible task; and well it might be, were it not for the fact that the human ear is not an extremely sensitive organ. It cannot register smaller intervals of time than one-fifteenth of a second. This simplifies the problem considerably, because if we take the speed of sound as, roughly, 1,100 ft. per second, it is obvious that a difference of 70 ft. to 80 ft. (the distance sound travels in one-fifteenth second) in the paths of any rays can be allowed before echoing, or overlapping, will become noticeable. Again, from long necessity, our ears have become used to a certain amount of overlapping of sounds, so that now, if it is not present, as in an open-air speech, an unaccustomed and irritating feeling is produced.

To amplify the foregoing, let us examine some surfaces and see their effect on the distribution of sound energy.

Taking the plan of a plain, rectangular building, with a source of sound at S (Fig. 3), and plotting a pencil ray, as shown, it is found that it is reflected many times across the room from side to side. If, however, we slope the walls on the side of the source, as shown at AA, Fig. 4,

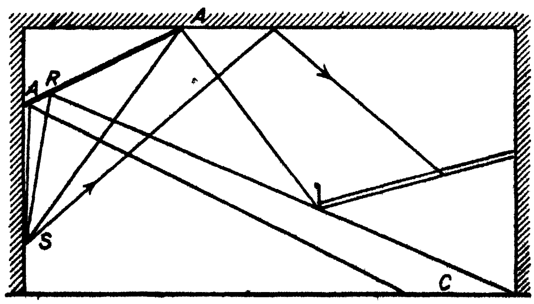


FIG. 5. LONGITUDINAL SECTION OF HALL

we get our ray reflected almost straight down the body of the hall, which, of course, makes for even distribution.

Fig. 5 is a longitudinal section of a rectangular hall having an overhanging gallery at one end. With the source at S, it will be seen that the gallery acts as a screen over the lower part of the hall, and prevents useful reflections from the ceiling reaching it. If, however, we slope the

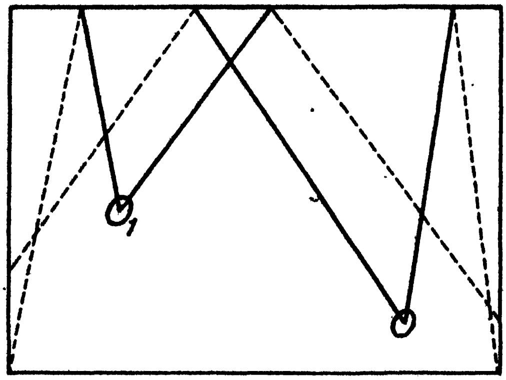
ceiling, as shown at AA, above the source, then we can arrange to throw the sound right underneath the gallery and, provided the path of the reflected sound, SRC, is not greater than SC by more than 70 ft. to 80 ft., excellent results will be obtained.

These two cases are, of course, very elementary, but they serve very definitely to show how even distribution is affected by the shape of bounding surfaces.

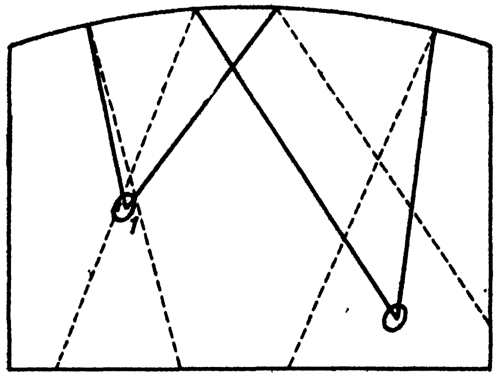
Now suppose that our auditorium is a multi-sided figure, it is obvious that we shall get reflections in all directions, and that these reflections will be constantly crossing each other, which will tend to produce patches of maxima and minima sound, according to whether the reflections are reinforcing or destroying each other. Where this seems likely to happen to any great extent, reflection must, as far as possible, be stopped by making the reflecting surfaces absorbent.

This gets rid of one difficulty but raises another because, by stopping reflection, we are also stopping reinforcement which the reflection will produce. It is, therefore, necessary to obtain this reinforcement by reflection from other surfaces—surfaces which will give even distribution with consequent even reinforcement as, say, the ceiling.

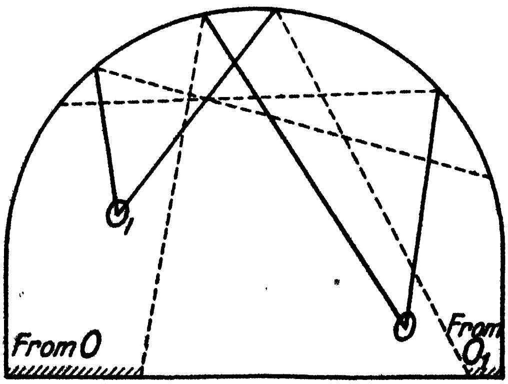
As regards reinforcement obtained in this direction, naturally a flat ceiling gives the best results, for, where a curved ceiling is employed, the steeper the curve the more concentrated are the reflections from it. In actual practice, where a curved ceiling must be employed, a safe rule is to use a radius of curvature of not less than twice



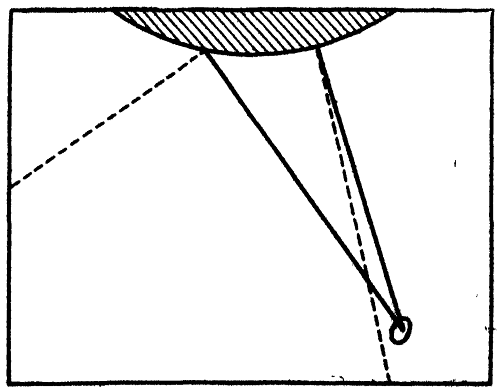
Flat Ceiling
Showing how the sound from a source in any position is evenly distributed. O and O_1 are for a speaker at floor and gallery level



Curved Ceiling; radius twice the height
Showing how a curved surface tends to concentrate sound after reflection. The reflecting areas are the same as for flat ceiling, but the areas covered by the reflected sound are reduced by about 50 per cent



Barrel Vault
Showing concentration caused by steep curves. Only hatched portion of floor receives reinforcement by reflection



Convex Surface
Showing the dispersal produced. Such surfaces can at times be usefully employed in ceiling coves, etc.

Fig. 6. Effects Produced by Various Types of Ceiling

the height of the ceiling. Spherical and barrel vault ceilings are always dangerous (see Fig. 6).

Clarity. From what has already been said about reverberation, it is clear that where the period is at all prolonged it must tend to blur reception, because, as the normal rate of speech is about 4 syllables per second, we find, assuming a reverberation of 4 seconds, that the first syllable uttered is still contributing a certain quantity of sound when the speaker has arrived at his fifteenth syllable, while the intermediate ones are also giving their quota. There is, therefore, a jumble of syllable sounds through and above which it is necessary to hear the orderly precession of speech. This point must be well understood, because the bulk of acoustical problems resolve themselves into regulating this period of reverberation

After many years of research, Professor W. C. Sabine, of Harvard University, U.S.A., to whom we are not only indebted for the first serious investigations, but also for much of our fundamental data, was able to produce a formula connecting the volume of a room with its reverberation. This has now become standard, and is of paramount importance.

SABINE'S REVERBERATION FORMULA. If T is the reverberation in seconds, K a constant $= 0{\cdot}05$, V the volume, and A the absorbing power of the room, then $T = \dfrac{KV}{A}$

In this formula, A is computed by totalling the areas of the various materials employed in the finishing of the bounding surfaces; for example, the areas of plaster, wood, glass, carpets, number of seats, and the type and number of audience, and multiplying each by their respective coefficients of absorption; this gives the number of absorption units each is supplying, and the sum of all these is the *total absorbing power* in open window units.

In certain special cases requiring a very "dead" effect, Sabine's formula has been found not to be sufficiently accurate and was modified by C. F. Eyring to—

$$T = \frac{K\,V}{-\,s \log_e (1 - a)}$$

Where S is the total surface area in the room and a is the average coefficient of absorption got by dividing total surface area S by total absorption A.

As already shown, the human ear, by long necessity, has become used to a certain amount of overlapping of tones, so that, bearing this in mind in dealing with the control of reverberation, it is necessary to decide what time to allow in order to secure the best results; for, if too long a period is given, blurring will take place, while, if it is too short, the sound will be apparently lifeless. After investigating a large number of good auditoriums, limits of from 1 to $2\frac{1}{2}$ seconds have been found to be very successful.

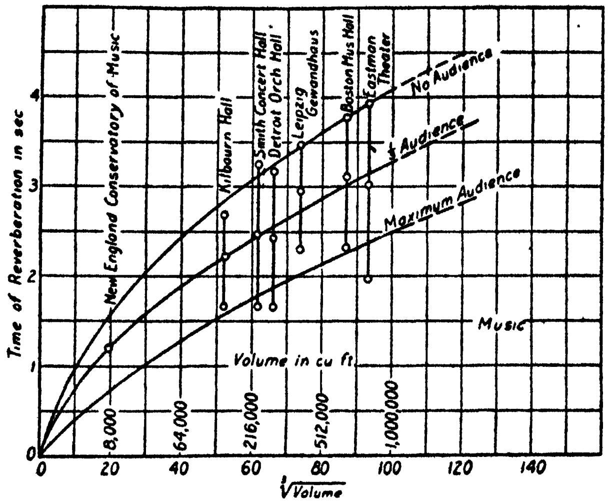


FIG. 7. RELATION BETWEEN VOLUME AND TIME OF REVERBERATION OF VARIOUS AUDITORIUMS

The graphs in Fig. 7, published by permission of Professor F. R. Watson, of the University of Illinois, show the relation between volume and the time of reverberation for certain auditoriums whose acoustics by common consent are pronounced good.

This somewhat wide range is made necessary by considerations of the volume, the type of building, and the use to which it is to be put; that is, whether it is to be used mostly for speech or music, or both. For buildings of large cubic contents, a lengthy period is desirable in order to assist the sound in completely filling the volume. On the other hand, when the longer periods are employed, it is necessary for a speaker to check his natural speed of utterance and be more deliberate if he is to be clearly and distinctly heard, for the longer the reverberation, the more will the sounds overlap each other, with consequent blurring.

As regards the various uses of a building, we have seen that speech requires a fairly short

period of reverberation. Music, on the other hand, requires a longer one to secure the best effect, because the essence of music is the blending of tones. A piano or violin in the open air always sounds dull, as each note dies almost as soon as it is produced, thus getting no chance of blending with the succeeding ones to enrich the whole volume. For music, then, a reverberation of up to 2½ seconds is often found desirable.

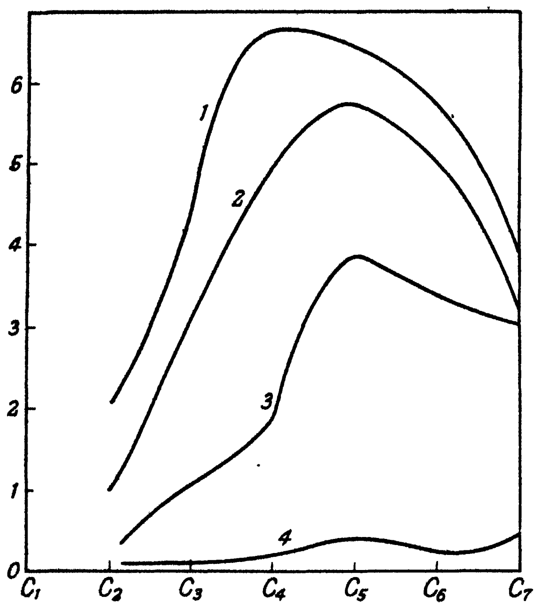


FIG. 8. ABSORPTION GRAPHS

1 = Cabot's quilt covered with canvas
2 = Uncovered felt
3 = Acoustic plaster
4 = Ordinary lime plaster

When the auditorium is to be employed for both speech and music, a happy medium between the two limits given should be chosen, say 1½ to 1¾ seconds. Calculations are usually based on a two-thirds capacity audience.

Pitch and Tone. The last condition, namely, that the sound should reach the auditors in the same pitch and tone as it was produced, or, in other words, should receive accurate rendering, applies entirely to music, and is probably one of the most difficult problems to be encountered in acoustics, because there are so little definite data available. It is a well-known fact that in some buildings a discord may be produced, yet its echo or reverberation may be found to be in harmony, or vice versa. Or, again, a particular note may be sustained while an observer moves about from point to point recording the apparent pitch of the sound, and he may well find that the note in one place is sounding an octave above the recorded pitch at another.

Absorption, reverberation, and resonance must all be considered in connection with accurate rendering. As we have seen, all materials are capable of absorbing sound, but the amount which they absorb depends on the pitch of the sound. The *absorption graphs* (Fig. 8) of many materials are more or less of the inverted parabola type, with their maxima at middle C, or an octave above it, showing that the energy of the lower and the higher notes is not so readily dissipated as that of notes in the middle register.

ABSORPTION. As all the usual wall finishes have coefficients of absorption of not more than ·05 for middle C, any reduction in this figure that there may be in the higher or lower registers cannot make any appreciable difference. It is only when considering materials with high coefficients of absorption that care must be taken to use only those with the highest *average* coefficient. The period of reverberation in any hall will, of course, vary as the pitch of the sound varies, so that if the three notes C_1, C_3, and C_5 are played together, their tones blending, the effect produced by the reverberation may be quite different, because C_3 is absorbed quicker than either C_1 or C_5, which consequently go on sounding after C_3 has entirely disappeared.

REVERBERATION. For buildings to be used for the production of music, the time of reverberation is also of great importance, for on it depend the weight and tone of the music, that is the number of actual notes that will be contributing their quota to the total volume of sound at any particular moment. Supposing a piece of music is played in a building with a reverberation of 2 seconds, and then in another with a reverberation of 4 seconds; in the latter case the sound from twice the number of notes will be audible at any specific moment, with possibly most disastrous results.

Composers have been very alive to these effects and depend particularly on reverberation to get their weight of tone; in fact, some authorities go further and say that to hear a piece of music rendered as the composer intended, it is necessary to hear it played in the building in or for which it was composed. This is reputed to be the case with some of Fairfax's work, which is supposed to have been written specially for St. Albans Cathedral.

RESONANCE. Resonance, because of its unbalancing effect, is also of some importance in

providing accurate rendering, but as no controlling means has yet been discovered, resonance is still more or less a matter of chance. As, however, before any marked effect can be produced, it is necessary for the resonant materials in the room to function on the same note, it is seldom that any really serious defects are produced in this way. When, however, it does occur, as might conceivably happen in a room in which there is a large area of wood panelling, steps must be taken to render the panelling non-resonant by filling in solid behind it. This would have a similar effect to putting a towel into a big drum.

To sum up, it can be stated that the provision of good acoustics in any auditorium depends both on its design and on the furnishings applied to its surfaces.

Absorbent Materials

Before taking a practical example, the question of the best absorbing materials to use for the reduction of reverberation must be considered.

The ideal absorbing material should be one possessing a uniformly high coefficient of absorption over the octaves C_1 to C_7. It should be a structural material easily applied, and one capable of being adapted to harmonize readily with the general scheme of decoration of the whole building; and, lastly, it should admit of cleaning and redecorating in the usual way.

Like most ideals, 100 per cent is not attainable, but there are many materials available which do approach within measurable distance. These may be conveniently divided into three categories—

1. Materials manufactured on a cementitious base. In this class come the special acoustic plasters and acoustic stone. These materials are structural and the latter, which is integrally coloured to almost any shade required, can be obtained in any size up to 36 in. × 15 in. Decoration of the plasters is by special paint, applied by spraying.

The use of these materials is, in general, limited to new buildings.

2. Materials of a soft nature. These can be used only on areas where they are not likely to be damaged.

This class includes acoustic boards, fibre tiles, asbestos spray, eel grass and other quilts, slag wool, etc.

These materials may be used both on new work as well as existing, but they are not as structural as the plasters and stone. They are, however, more acoustically efficient when used in thicknesses of 1 in. upwards.

3. This class is really a combination of the other two, in that the actual absorbing material is of the soft, highly efficient variety, over which

Fig. 9. Example of Acoustic Correction
Cabot's quilt was fixed in the dome and on the wall under the arch and the whole was screened with canvas, which was thinly distempered to match the existing decorations

is applied, either as an integral part or as a separately fixed face, a hard cementitious or metal face. This hard face must, however, always be perforated with holes in the order of $\frac{1}{8}$ in. diameter. These materials may be used equally well in both new and existing buildings.

Acoustic work should never be obtrusive. Choose the material that will most readily fit in with the general decorative scheme. See Fig. 9.

Practical Work

As a practical example, let us suppose that we have a proposed auditorium to consider. It is required to seat 300, and it is of rectangular plan measuring 70 ft. by 30 ft., with a stage or rostrum at one end, no gallery being required. The building is to be used primarily for speech, but occasionally concerts will be held in it. From the dimensions given, it will be seen that the first essential of adequate loudness will

easily be fulfilled, because any speaker will be able to create sufficient volume of sound to fill it completely.

Distribution of Sound. The next consideration will be that of even distribution of the sound over the floor space. Here, again, owing to the simple shape of the bounding surfaces, no very complicated interference system can be set up through multiplication of reflections. The longest reflected paths of sound will come from the wall opposite the platform, and will measure 140 ft., or twice the length of the building, so that one-eighth of a second will elapse between a syllable being uttered by a speaker and its return to him from the back wall. This will give the impression of the voice being thrown back from this wall, but not sufficiently pronounced to give a distinct echo. This point should be remembered when the question of the reverberation is considered, for, should it be found necessary to introduce absorptive material, it is clear that a good place to put it would be on the back wall, to minimize the reflections from this surface.

Up to the present no reference has been made to the ceiling. But, if the architectural features of the hall permit, a flat ceiling, as already pointed out, will not only make for even distribution of sound, but also provide for the maximum reinforcement being given to the audience by reflections from it. Should a curved ceiling be required, then its radius should be kept as large as possible, not less than twice the height of the building; for, as we shorten it below this figure, we shall make for uneven distribution from it, besides increasing the volume of the building in greater proportion to the bounding area, which will adversely affect the reverberation. If it is found necessary to employ a steep curve, or a barrel vault ceiling, then the ceiling surfaces must be made absorbent in order to stop, as far as possible, reflection from them. The only other kind of ceiling which might be adopted is the open principle, or Gothic type. This would appreciably increase the volume, but as it would also give a corresponding increase in surface area, the reverberation would not be greatly affected. This type of ceiling does not help us with regard to the even distribution and adequate loudness, but as, in this case, the latter condition does not require reinforcement from the ceiling, it could readily be adopted if required.

Correcting Reverberation. Now, assuming that a flat ceiling has been chosen, and its height temporarily fixed at 40 ft., the requirements of reverberation must be investigated. As the building is required primarily for speech, with occasional music, we can say a reverberation of $1\frac{1}{2}$ would be suitable for the full hall.

Now, from the Sabine formula of

$$T = \frac{\cdot 05V}{A}$$

here $T = 1\frac{1}{2}$ and $\cdot 05V = 4{,}200$, so that A must $= 2{,}400$, that is, the total absorbing power of the room must be 2,400 open window units in order to obtain a reverberation of $1\frac{1}{2}$ seconds Towards this total absorbing power of 2,400, we have—

		Units
Audience	$300 \times 4{\cdot}0$	$= 1{,}200$
Wood floor, 70 ft. × 30 ft. .	$2{,}100 \times 0{\cdot}05$	$= 105$
Plaster walls and ceiling .	$10{,}100 \times 0{\cdot}025$	$= 252$
	Making a total of	1,557

For simplicity's sake, the area of glass has been ignored, and the window openings taken as being entirely covered over with plaster.

But we require 2,400 to give us our correct reverberation, so that if the assumed volume is essential, then we shall have to introduce 843 units. This could easily be done by employing one of the highly absorbent materials—such as Cabot's quilt, acoustic plaster, or hair felt—and this would mean in square feet an area of—

(1) $843 \div 0{\cdot}60 = \frac{843 \times 5}{3} = 1{,}405$ if Cabot's quilt is employed (the coefficient of absorption of quilt being 60 per cent open window units)

(2) $843 \div 0{\cdot}30 = \frac{843 \times 10}{3} = 2{,}810$ if acoustic plaster is used (the coefficient of plaster being 30 per cent open window units)

Further, if Cabot's quilt were adopted, the whole of this could be placed on the back wall of the building; and it would serve, if fixed there, not only to reduce reverberation, but also effectually to prevent sound being reflected from this wall to the annoyance of the speaker and the occupants of the front seats.

If acoustic plaster were adopted, it should be applied to this wall and the surplus area to the side walls.

If, on going into the question of the volume again, it is found that the height of 40 ft. might conveniently be reduced to 30 ft., then this would reduce the volume and $0{\cdot}05V$ would equal

3,150, which would reduce the total absorbing power of the auditorium to 2,100.

From calculation on the above figures, *A* would then be—

	Units
Audience	1,200
Wood floor	105
Plaster	202
Which gives a total of	1,507

This would only leave 593 units to be supplied by the particular absorbent decided on, as against 843 units in the first case.

So far, no value has been allowed for the actual seats, which may vary from 0·1 for chairs to 1 for, say, upholstered seats, the reason for the omission being that the case under consideration was that of the hall with its full complement of audience, for which the full allowance of 4 units per person was taken. Had the calculations first been based on the empty hall, then allowance would have had to have been made for the seats, but this allowance would, of course, have had to have been deducted from the 4 units per person. The supposition is that the effect of the seat was neutralized by a person sitting in it.

Up to now we have considered the question assuming the hall to be entirely filled. It may, however, often happen that the average attendance is, say, half the maximum capacity, so that the reverberation must be adjusted on these lines. Where possible, then, it is desirable that the audience should make little or no difference to the absorptive power of a building. That is, they shall take away by screening approximately the same number of units as they themselves are supplying. Thick carpets and heavily upholstered seats are the best means of arriving at this desirable state of affairs.

Remedying Defective Buildings. Next comes the proposition of the building which, when erected, is found to possess defective acoustics. Its treatment will fall under two headings—structural and physical—or what may be termed surgical and medical. The former, for obvious reasons, can be resorted to only in very extreme cases, when the interference system is setting up abnormal zones of maxima and minima sound. Structural work to alter the contours of a building is not a task which may be lightly undertaken.

In very many cases, however, it will be found that the chief cause of trouble is excessive reverberation, and this may, fortunately, be readily corrected. When plans of the building are available, its volume and the surface area of its bounding walls can be obtained, and this figure can be checked by actual measurement in the building itself. From this data can be calculated the number of units of absorption that must be added in order to obtain an acceptable period. These extra units can be supplied by introducing absorbent materials, while a study of the building will soon reveal the best place for fixing them, so that they may not only reduce reverberation, but also cut out any reflections that might militate against even distribution, or the production of echo.

Costs. These remarks on the cost of acoustical work can be only on very general lines, as the type and purpose of a building can alter the price so considerably. However, never will the cost per job be found prohibitive, for save in the most exceptional case, from 2 per cent to 4 per cent of the total cost will cover it. In two instances which recently came under my notice, a small school chapel and a large synagogue, the costs were £170 and £400 respectively. On the other hand, the cost per yard may seem at first sight to be somewhat high, varying as it does from 18s. to 27s. per yard super, according to the material employed, because the tendency is to compare the acoustical work with ordinary wall finishes, whose function after all is more or less only to cover up the bricks. If the price of acoustical materials is compared with that of any of the more ornamental and decorative wall finishes, such as oak panelling, marble, carved stonework, mosaic, and the like, the balance will be found to be heavily in the favour of acoustic materials. The cost of acoustic work should be regarded as a lump sum item, in the same way as heating, lighting or ventilation for, after all, it is the cost per building which must be set against the value of the work to the building that either justifies or rules out the expense.

Finally, surely no cost is too great to ensure that a building is really suitable for the purpose for which it has been erected.

Noise Insulation

Now let us turn to the other aspect of building acoustics, namely, the control of noise.

As a general definition, "noise" is taken to mean any unwanted sound originating either in or outside a building. It is recorded by the

listener's ears, responding to the sound vibrations which, for our purpose, are regarded as travelling through the air, bone transmission being ignored.

These air vibrations will be either primary or secondary, by which is meant those that travel directly through the air from the source to the observer, and those that, for part of their journey, travel through either the ground or the structure before being finally converted into air-borne vibrations to which the observer's ear responds. In the first category would fall traffic noises (e.g. buses in the street) entering through open windows; while the hum from an engine, in say a basement, would fall in the second category.

Units. In investigating "noise" problems, it is evident that some unit or units of measurement are necessary if loose definitions and inaccurate statements are to be avoided. Two units are, in fact, employed: the Decibel and the Phon. The decibel is the unit of mechanical energy and is, therefore, measurable by instruments with exactness; while the phon is the unit of loudness as registered by what is known as the "average ear." It is not, therefore, an exact unit, but is employed to place the loudness of a noise in a general category.

These two units are necessary because the same amount of energy used to produce two sounds of different pitches, i.e. a low and a high note, will not give to the ear the same sensation of loudness in both cases; or, expressed another way, an observer might say: "Those two sounds are about as loud as each other," but if one is of low pitch and the other high, more energy will have been expended in producing the former than the latter; thus, although the equivalent loudness (phons) is the same, the energy (decibel) varies. A phon is the smallest change in loudness that an average ear can detect.

The scientific definition of the two units given in the B.S.I. glossary of Acoustical Terms and Definitions, No. 661, of 1936, is as follows—

Decibel. Two sounds of the same character and of intensities I and I_0 (energy units) differ in intensity by n decibels (db.) when $n = 10 \log_{10} (I/I_0)$. A reduction of 1 db. is a reduction of the mechanical energy in approximately the ratio 1·26 to 1. A reduction of 10 db. corresponds to a reduction of the mechanical energy to one-tenth of its original value: a step of 3 db. corresponds to a reduction of one-half.

Phon. A sound is said to have an "equivalent loudness" of n phons if the sound is judged by a normal observer to be as loud as a 1,000 cycle pure tone of which the intensity (energy content) is n decibels above a fixed zero which is almost identical with the threshold of hearing, namely 0·0002 dynes per square centimetre.

Various authorities have assigned an equivalent loudness figure (phon value) for many everyday noises and this is given in the following table—

Rooms and Localities	Equivalent Loudness in Phons	Common Noises
—	130	Threshold of pain.
	120	Noisy aeroplane engine at 10 ft
Boiler maker's shop	110	—
Noisy tube train; Aeroplane cabin	100	Pneumatic drill, unsilenced; Noisy sports car and motor cycle; Express train at 12 ft.
Very noisy city street	90	Pneumatic drill, silenced; Motor horns, loud music
—	80	Trams; Accelerating buses; Loud radio music
Cinema theatre; Average city street; Noisy office	70	Radio speech; Average music; Noisy typewriters; Loud public speaking
Room with ordinary conversation; Quiet street; Train windows closed	60	Normal speaking voice; Noisy ball tap discharge
Quiet office; Quiet restaurant	50	Quiet saloon car; Upper limit for household noise
Quiet suburban street	40	Low radio music
Quiet garden	30	Average domestic noise
—	20	Whispering
—	10	Rustle of leaves in slight breeze
	0	Approximate threshold of audibility

One further aspect needs consideration before we can pass on to practical application. This is masking effect.

A noise entering a dining-room during the day may hardly be noticeable because it is very little louder than the general noise level in the room itself, but the same noise entering a bedroom at night would cause considerable annoyance because of the bedroom noise level being so much lower. In other words, the incoming noise is masked by the noise in the room, so that it is the loudness difference which is the crux of the matter. Now, what is to be done about it? The ideal is that perfect insulation is achieved by perfect isolation which, as Euclid might say, is impossible; or, at any rate, commercially impossible. But that is the aim, and the closer one gets to it, the better the results.

Primary Air Vibrations. Air-borne noise presents the easier problem, so we will consider it first, under the heading of Traffic Noise. In this, the problem is to reduce the intensity of noise entering rooms from outside. Now, if windows are to be open, a certain percentage of

sound must travel directly from its source to the observer, and with this nothing can be done; but the remainder, having passed through the window, must be reflected by the bounding surfaces of the room to the observer before he will hear them, and according to how well they act as reflectors will depend how much noise will be heard. If, therefore, the walls and ceiling are covered with highly sound-absorptive materials, then the noise level in the room will be appreciably reduced because of the reduced reflection of the bounding surfaces.

If windows can be kept permanently closed, less noise will enter, with a consequent improvement. If this is done, however, artificial ventilation will be needed.

Further improvement can be made by the use of double windows, glazed with plate glass; but, for best results, separate frames should be used, spaced not closer than 6 in. Brick the windows altogether and more noise will be excluded—but what a room!

Secondary Air Vibrations. Finally, we come to the reduction in noise, both air-borne and structurally borne, passing through walls and floors. Remember—isolation is the key factor.

FLOORS, Wood Joist. Use an insulating material between the floor boards and wood joists, carrying it round the ends of the boards so that they do not touch the walls. In this construction the isolation is broken, because each nail is driven through the floor boards into the joist.

Secondly, use a batten on top of the insulating material, nailing it to the joists only at wide intervals. Then nail the floor boards to the batten. This method can also be used on the soffit of joists to carry the lathing for plastered ceilings.

Increased reduction of air-borne sounds only can also be secured by packing between the joists with some suitable material. This, of course, can be combined with either of the two preceding methods.

FLOORS, Concrete. The above methods can also be used in concrete floors. Alternatively, the insulating material may be laid on the structural concrete floor and then a concrete screed 1½ in. to 2 in. thick laid on top.

WALLS, Timber Studding. Treat as for floors, using battens to carry the lathing.

For better results use staggered studding, so that the connection between the two faces of the partition is completely broken, except at head and cill.

WALLS, Brick, Slab or Tile. Double partitions are better than single walls, provided that—

1. The total weight of the double partition is not less than the weight of the single partition.

2. That the two "skins" are not joined together, i.e. wall ties are not used nor is the space between filled with mortar droppings.

Either double or single partitions may be treated on their faces as studded partitions and, in addition, cavity walls may have the cavity filled with sound-absorbing material. In this connection it should be remembered that when a loose packing material is used it will always settle and, also, it is generally impossible to fill the top few inches.

A last reminder—whenever possible, plan acoustical work ahead of construction—it saves costs and almost always produces better results.

Architect's Office and Routine

By Herbert J. Axten, F.R.I.B.A.

Chapter I—OFFICES AND EQUIPMENT

It not infrequently occurs that two architects unite in practice, the one being possessed of a pronounced architectural ability, the other—though not devoid of that ability—having a greater development of business acumen, and therefore a leaning towards the administrative side. This is a happy combination, and usually results in the building up of a successful architectural practice.

Taking a partnership of this nature for consideration, the chart given in Fig. 1 shows the activities under the care and supervision of each of the principals.

Office Accommodation. Assuming two architects are in partnership the following office accommodation is necessary—

Private office for senior partner (business).
Private office for junior partner (architectural and works).
Small drawing office for senior assistant.
Large general drawing office.
Small waiting-room for callers—if possible.
Typist's, correspondence, and filing-room.

A provincial office would require a photo-printing room, which might also serve as a store for samples of building materials, strainers for competition drawings, spare trestle drawing tables, storage of drawings, and documents of completed jobs, etc.

The equipment of the offices will necessarily vary with the financial standing of the principals, but the following is the general arrangement of a medium grade suite.

Senior Partner (Business). This being the office in which clients are received but in which no actual drawing is done, the principal furniture is—

Large writing table with pedestal drawers and writing accessories, and armchair.
Two large lounge armchairs and a few small chairs.
Table upon which plans may be opened for perusal and discussion.
Bookcase and books, stationery cabinet, letter trays.
Safe for private documents.
Turkey carpet, hat and umbrella stand, clock, and permanent date calendar.

Junior Partner (Architectural and Works). This being the office of the partner more intimately concerned with the preparation of drawings and the supervision of works in progress, the principal furniture is—

Large drawing desk.
Chest of drawers sufficiently large to contain double elephant drawings.
Writing table with pedestal drawers.
Stationery cabinet and writing accessories.
Armchair, small chairs, and carpet.
Bookcase, letter trays, clock, and permanent date calendar, technical books and periodicals.

Drawing Offices. Following is the equipment of these offices—

Drawing desks or tables with large plan drawers.
Stools.
Plan drawer cabinets to take double-elephant drawings.
Nest of drawers or filing cabinets for manufacturers' catalogues, and plates from architectural and building periodicals.

T-squares.	Railway curves.
Set-squares.	French curves
Beam compasses.	Perspectograph.
Water colours.	Planimeter.
Pallets and brushes.	Clinograph.
Stickphast and sponge.	Mahogany straight edges.
Whatman drawing paper.	French chalk.
Cartridge drawing paper.	Dusters.
Detail drawing paper.	Stencils and rubber stamps.
Squared paper.	Pencils, pens, and coloured crayons.
Tracing paper.	Slide rule.
Tracing linen.	Drawing pins.
Indian ink.	Coloured and writing inks.
Theodolite and tripod.	2 ft. rules.
Level, tripod, and staff.	Sketch blocks.
Surveyor's chain and arrows.	Sketch books.
100 ft. tape.	Notebooks for recording visits to jobs.
Surveying book.	
Levelling book.	

Typist's and General Office. The equipment here is as follows—

Typewriter, table, and stool.	Safe, clock.
Stationery cabinet.	Shelving.
Clerks' desks and chairs.	Letter trays.
Vertical filing cabinets.	Writing and filing accessories.
Vertical card indexes.	Duplicating machine.

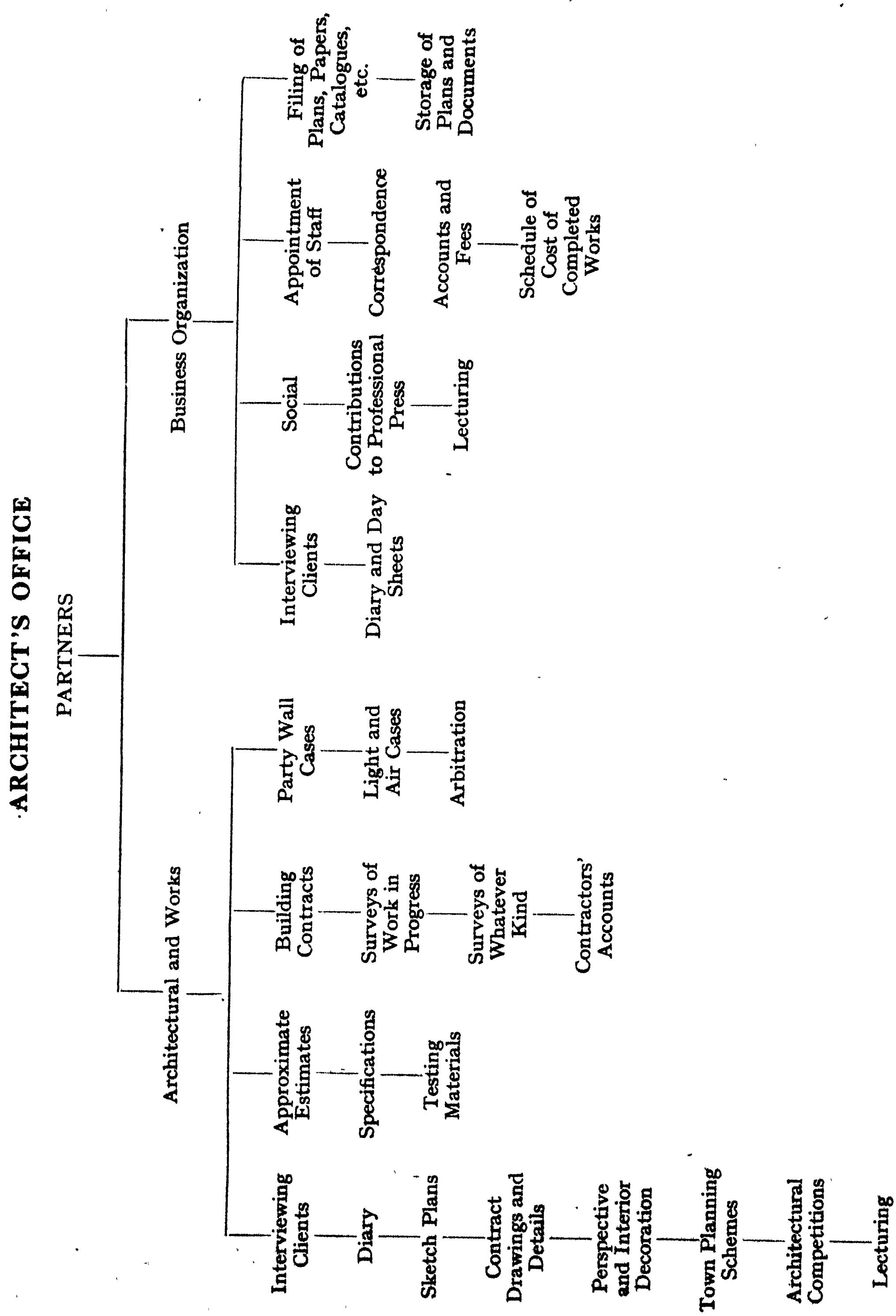


FIG. 1. CHART SHOWING THE ACTIVITIES OF ARCHITECT'S OFFICE

The staff required to man an architect's office efficiently comprises—

- Senior (or managing) assistant.
- Architectural assistants.
- Clerks and shorthand-typists.
- Office boy.

Duties of Architectural Staff. The duties of the *architectural members* of the staff vary of necessity with the size and importance of the office on the one hand, and with the actual amount of architectural work executed by the principals on the other.

Should there be only one principal, he may not have sufficient time to execute the original designs for every job undertaken, and in that case the senior or chief assistant would prepare the sketch designs in addition to his other duties, but in the case of the architectural partnership, already referred to, the following might be a brief outline of the duties expected to be undertaken by the architectural assistants.

The client's instructions having been given and formally acknowledged, the principal, accompanied by the senior assistant, would visit the site and prepare sketch designs, plans, and elevations. Upon these being approved by the client, they would be handed over to the senior assistant. From this point onwards until the completion of work, the senior assistant would be strictly responsible for the preparation of all the necessary contract drawings, details, and other drawings, including obtaining necessary information and particulars from the site and from the local and other authorities, for all of which purposes he is assisted by the remainder of the staff as and when required. In the case of a small job, one or other of the assistants may be given the work, and under the guiding hand of the senior assistant made responsible for its satisfactory execution; in this way the juniors gain experience and self-reliance.

The senior assistant must also be capable of making land surveys and taking levels; making surveys of dilapidations; making sanitary surveys; making surveys for valuation regarding the purchase or sale of various types of properties; measuring up and drawing out existing buildings requiring alteration or extension. He must also be well versed in the national and local legislation affecting the construction of buildings, in order to discuss intelligently all matters with his principals; prepare drawings that will not infringe any Acts or by-laws; supervise the execution of the work; examine and test the building materials being used upon a job; prepare specifications and approximate estimates; inspect buildings during the progress of erection and completion, for the issuing of certificates for payments to the builder and sub-contractors; adjust contractors' accounts.

The other architectural assistants are required to carry out preliminary and other work required by the senior assistant, for the purpose of expediting the work of the office, for example—

- Assist in all survey work;
- Work out the levels in the field book;
- Plot simple work;
- Prepare tracings in ink or pencil;
- Enter up the "jobs" book;
- Enter up "plans" register;
- Enter up all plans sent out and returned;
- Colour working and other drawings;

No.	Date	Subject Matter	Client	Remarks
239	2/2/46	Proposed Warehouse, Riverside, Northampton	Hardware Manfg. Co.	
240	4/2/46	Survey and Report, Proposed Purchase of Factory, Slough	Central Eng. Co., Ltd.	
241	5/2/46	Proposed Detached House, The Grove, Ealing	A. Client	Scheme Abandoned after Sketch Plans Prepared
242	8/2/46	Dilapidations—6 Houses, St. George's Square, N.W.2	Quill & Co. (Solicitors)	

FIG. 2. "JOBS" BOOK

Prepare schedule and analysis of cost of completed works.

Arising out of the last-named item the books given below call for explanation.

"JOBS" BOOK. This book is kept for the purpose of recording every "job" as it comes into the office, whatever its nature.

The jobs are entered in order of date and given a "number," which they retain throughout their progress; all the drawings and correspondence bear this number, as also does the "jacket" containing the papers when put into the store.

Fig. 2 shows a specimen of entries in the jobs book.

PLAN REGISTER. As its title infers, this book is for the purpose of registering all drawings prepared. The pages are headed with the number of the job obtained from the "jobs" book, the nature of the work, and the name of the client.

All plans are numbered in accordance with this register and also bear the job No., thus—

Job No. 239 Drawing No. 3

The entries are made in tabulated form, of which Fig. 3 illustrates a typical page.

PLANS "SENT OUT" BOOK. In this book a record, in order of date, is kept of every drawing sent out of the office; in it is entered the name of the person to whom the drawing was addressed, the date noted upon which it was returned, and any remarks thereon. Fig. 4 shows the "ruling" of this register.

SCHEDULE OF COST OF COMPLETED WORKS. A schedule and analysis of the actual cost of completed works may be kept under the following headings: cost per foot cube; per foot super of floor space; per room; per scholar; per "sitting"; per bed; per car; and so forth. This forms an exceedingly useful addition to the working data in forming the basis of the preparation of approximate estimates.

Duties of Business, or Clerical, Staff. The "*business*," or *clerical*, staff and office boy carry out all the typing, correspondence, filing, and storage of documents and drawings. This involves the keeping of the following books—

LETTER REGISTER. A letter register is kept in which is recorded day by day the letters received; these are stamped with a rubber stamp bearing the date and serial number of the letter.

POSTAGE BOOK. This book is for keeping a record of the postage of all letters and parcels, and of the expenditure upon stamps. The money for the purchase of the stamps is drawn from "petty cash," and a check between the postage book and the petty cash book is made from time to time.

TELEPHONE BOOK. In this book are recorded all the outgoing calls on one side of the page, and all the incoming calls on the other side. The former not only serves as a record of a telephone conversation, but may also provide a method of approximately checking the Post Office quarterly account of charges.

CALLERS' BOOK. In this book is recorded day by day the time and names of the several callers, with a short title of the matter to be discussed. Fig. 5 shows an example of the ruling.

DIARIES. The diaries kept by the principals are only a record of appointments giving the time, name of caller, and subject-matter. The details of the interview are written upon separate day sheets, and filed with the documents relating to each particular job.

The diaries kept by the assistants record the time spent upon each and every matter dealt with, and their "petty cash" expenditure thereon. These items are afterwards transferred by a clerk to the day sheets, for the purpose of obtaining complete records of the jobs, and for checking the expenditure thereon with the fees received therefrom.

DAY SHEETS. These are virtually very detailed diary entries of every item in chronological order respecting each job. In these are entered the particulars of all interviews, instructions, correspondence, assistant's time in the preparation of drawings, surveys, visits to works, petty cash expenditure, etc.; in fact, everything appertaining to the carrying out of the particular job.

These sheets are kept posted up by a clerk who extracts, day by day, items from the assistants' diaries, postage book, and telephone book—the report of interviews and instructions being dictated by the person concerned to a stenographer, who writes them up. In this way a comprehensive record of the progress of the negotiations, deliberations, and procedure of the work is kept; and when "priced out" it serves as a very useful basis for the preparation of accounts for professional charges, especially regarding matters which do not come under a direct percentage charge; it also serves as a very useful check where the percentage charge is applicable.

A member of the clerical staff is also responsible for keeping the account books, and for preparing and issuing accounts for fees. For this purpose the following books are necessary—

PETTY CASH BOOK. Entries in this book are of small expenditures, each usually under 20s., for which it is unnecessary to draw a cheque, such as travelling expenses, postage stamps,

WORK No. 239

PROPOSED WAREHOUSE, RIVERSIDE, NORTHAMPTON, FOR HARDWARE MANFG. CO.

No.	Date	Drawings	Copy Sent to	Date Sent	Date Recd.	Remarks
1	4/2/46	22 Scale Site Plan Plotted from Survey				
1A	5/2/46	Tracing of ditto, but Showing Proposed Road Widening	Office Copy			
1B	5/2/46	Linen Tracing of No. 1A . . .	N'ton Boro' C'n'l	5/2/46		Appd. 12/2/46
2	5/2/46	⅛ in. Scale Pencil Sketch Plans and Elevations	H. M. & Co. .	8/2/46	11/2/46	Appd. Subj. to Slight Amendts.
3	12/2/46	Complete ⅛ in. Working Drawings and Block Plan				
3A	19/2/46	Linen Tracing	O. C.			
3B	22/2/46	Photo Copy on Linen . . .	N'ton Boro' C'n'l	22/2/46		Appd. 27/2/46
3C	22/2/46	Photo Copy on Linen . . .	O. C. . .			Contract Copy
3D	22/2/46	Photo Copy on Linen . . .	Contractor .	8/3/46		By Hand
3E	22/2/46	Photo Copy on Paper . . .	Contractor .	8/3/46		By Hand
3F	22/2/46	Photo Copy on Paper . . .	O. C.			
3G	22/2/46	Blue Print	Heating Engrs. .	22/2/46		For Estimate
3H	22/2/46	Blue Print	Electrical Engrs.	22/2/46		For Estimate

FIG. 3. PLAN REGISTER

Date.	No.	To Whom Sent	Date Retd.	Remarks
5/2/46	239/1B.	Northampton Borough Council . .		Approved 12/2/46
8/2/46	239/2	Hardward Manufacturing Co. . .	11/2/46	Approved Subject to Slight Amendments

FIG. 4. PLANS "SENT OUT" BOOK

Date	Time	Name of Caller	Subject	Seen By

FIG. 5. CALLERS' BOOK

adhesive stamps for contracts, forms of contract, and the many minor articles required in an office from time to time.

JOURNAL. This book is now chiefly used for the opening entries when a new set of books is commenced, and for closing entries when the books are balanced. It is also used for entries other than cash transactions.

The journal is a book of original entry; that is, if an entry is to be made in the books and it does not involve the receipt or payment of cash, the entry must first be made in the journal. If, however, the entry is a cash transaction it may be entered direct into the cash book, and posted from there to the ledger. The form of ruling for this book is shown in Fig. 7.

CASH BOOK. This book, as its name implies, is a record of cash transactions, but strictly it is a ledger account which, for convenience only, is usually kept in a separate book. It also partakes of the nature of the journal, inasmuch as all cash entries are made direct into the cash book without first passing through the journal.

Receipts and payments are entered in this book—on the *debit*, or left-hand, side if a receipt, and on the *credit*, or right-hand, page if a payment.

At stated intervals, usually of one month, the bank pass book should be examined and checked with the cash book; and all charges made by the bank, e.g. for cheque books, etc., should be credited to the cash book and debited to a suitable ledger account headed "Bank Charges." The balance of the pass book will then equal the balance of the cash book. Fig. 6 is the usual form of cash book.

LEDGER. The ledger contains particulars of all business transactions with other persons, and of all charges against the business. A summary of the ledger accounts will reveal the exact position of a business or practice on a given date. The ruling of the ledger is identical with that given for the cash book.

Specimen Accounts. To illustrate the use of these accounts, a typical example is given, showing how the various items are entered in the books—

1. Feb. 1. 1946. A B instructed to act as architect for C D; on this date the builder signed the contract for the erection of a building for the amount of £40,000.
2. Feb. 10. C D (the client) pays two-thirds of the architect's fee, i.e. two-thirds of £2,400 = £1,600.
3. Feb. to August. Architect's out-of-pocket expenses chargeable to his client (C D) amounted, during this period, to £150.
4. Feb. to August. Architect's expenses, chargeable to the practice, amounted, during this period, to £28 10s.
5. August 31. Maintenance period ends; it is found that extras on the contract amounted to £1,000.
6. Sept. 3. Architect sends in his account, amounting to £825.
7. Sept. 10. Client offers architect £750 in full settlement, which is accepted, and paid on this date.

These items will be found entered in the various accounts in Figs 7 and 8.

Commencing with item No. 1, the first entry is in the journal, because though no cash passes, the client (C D) becomes liable, upon the signing of the contract, for the payment of two-thirds of the architect's fee. Thus, in the journal, the entry will be—

Feb. 1.	C D . . . . *Dr.*	£1,600	
	To Professional Services .		£1,600

The reason for this entry is that the architect is giving his services, and the client is receiving them; therefore the account which *gives* must

Dr. CASH BOOK *Cr.*

Date	Details	Fol.	£	*s.*	*d.*	Date	Details	Fol.	£	*s.*	*d.*

FIG. 6. RULING FOR CASH BOOK

be credited, and the account which *receives* must be debited.

On 10th February (item No. 2) this amount is paid; consequently the account which gives (i.e. C D) must be credited, and that which receives (i.e. cash) must be debited.

Item No. 3. The amount of £150 would be entered in small amounts, covering the period in question, but for the sake of brevity it has been entered here in one sum. The principle, however, remains the same. Payments out must be credited to cash, and debited to the account which is liable for these payments, or the goods or services which such payments represent. This sum, therefore, must be debited to the client and credited to cash.

Item No. 4 represents a sum of money which is not chargeable to the client, but to the practice. The entry, therefore, will be—

Office Expenses . *Dr.*	£28 10 –	
To Cash . . .		£28 10 –

Item No. 5. At the end of the maintenance period it is found that extras amount to £1,000, on which the architect is entitled to charge 2½ per cent, i.e. £25. The cost of the building, therefore, amounted to £41,000; on this sum the architect is entitled to £2,425, i.e. 6 per cent on £40,000, the amount of the accepted tender, plus 2½ per cent on £1,000, being the amount of the extras. He has, however, received £1,600,

JOURNAL

Date	Particulars	Fol.	*Dr.* £	*Dr.* s.	*Dr.* d.	*Cr.* £	*Cr.* s.	*Cr.* d.
1946 Feb. 1	C D . . . . *Dr.*		1,600	–	–			
	To Professional Services					1,600	–	–
	Being two-thirds of fee for building at Enfield.							
Aug. 31	C D . . . . *Dr.*		800	–	–			
	To Professional Services					800	–	–
	Being balance of fee for building at Enfield.							
Aug. 31	C D . . . . *Dr.*		25	–	–			
	To Professional Services					25	–	–
	Being 2½% on £1,000 extras on building at Enfield.							
Sept. 3	Professional Services . . . . *Dr.*		75	–	–			
	To C D					75	–	–
	Being agreed deduction from total fee.							

CASH BOOK
(A Ledger Account Kept in a Separate Book)

Dr. | *Cr.*

Date	Details (of *Receipts*)	Fol.	£	s.	d.	Date	Details (*of Payments Made*)	Fol.	£	s.	d.
1946 Feb. 10	To C D (two-thirds of Fee).		1,600	–	–	1946 Feb. –	By C D (being Sundry Expenses) . . .		150	–	–
Sept. 10	„ C D (Agreed Balance of Fee) . . .		750	–	–	Aug. 31	„ Office Expenses . .		28	10	–
						Dec. 31	„ Balance . . .		2,171	10	–
			£2,350	–	–				£2,350	–	–

FIG. 7. JOURNAL AND CASH BOOK WITH SPECIMEN ENTRIES

and so there is a balance due of £825. There must, therefore, be a journal entry, as follows—

Aug. 31.	C D	*Dr.*	£800	
	To Professional Services .			£800
	C D	*Dr.*	25	
	To Professional Services .			25

On 3rd September (item No. 6) the architect sends in his account. The client thinks this is rather large, and they talk over the matter, and eventually agree to a payment in full settlement of £750. This means, in effect, that professional services account has not given services represented by £2,425, but only £2,350; consequently this account must be debited with £75 (the amount which the architect has agreed to forgo) and the client must be credited with a similar sum, as if he had actually paid it. This adjustment must be made by means of the journal.

On 10th September the client pays the £750, and the entry in the books, therefore, will be—

Debit Cash
Credit C D.

LEDGER ACCOUNTS

C D (the Client)

Dr. *Cr.*

Date	Details	Fol.	£	s.	d.	Date	Details	Fol.	£	s.	d.
1946						1946					
Feb. 1	To Professional Services A/c		1,600	–	–	Feb. 10	By Cash		1,600	–	–
Feb. –	,, Cash (being Sundry Expenses) . . .		150	–	–	Sept. 3	,, Professional Services A/c		75	–	–
Aug. 31	,, Professional Services A/c		800	–	–	10	,, Cash		750	–	–
,,	,, Professional Services A/c		25	–	–	10	,, Cash (Expenses) .		150	–	–
			£2,575	–	–				£2,575	–	–

OFFICE EXPENSES

Dr. *Cr.*

Date	Details	Fol.	£	s.	d.	Date	Details	Fol.	£	s.	d.
1946						1946					
Feb. –						Dec. 31	By Balance . . .		28	10	–
Aug. 31	To Cash		28	10	–						

PROFESSIONAL SERVICES ACCOUNT

Dr. *Cr.*

Date	Details	Fol.	£	s.	d.	Date	Details	Fol.	£	s.	d.
1946						1946					
Sept. 3	To C D (Agreed Reduction of Fee) . . .		75	–	–	Feb. 1	By C D (two-thirds of Fee).		1,600	–	–
Dec. 31	,, Balance . . .		2,350	–	–	Aug. 31	,, C D (Balance of Fee) .		800	–	–
						,,	,, C D (Fee due on Extras)		25	–	–
			£2,425	–	–				£2,425	–	–

FIG. 8. LEDGER ACCOUNTS

Chapter II—PROFESSIONAL PRACTICE AND PROCEDURE

Work of an Architect. The present is becoming more and more the age of the specialist, and it is therefore not surprising that the practice of architecture comes also within this sphere. We find certain architects specializing in the design and construction of factory buildings, others in theatres, ecclesiastical work, and so forth; but the writer feels it will be more generally useful to concentrate attention here upon the activities of the office of the architect carrying on what might be termed a general practice. Within the scope of this section of the work, it would be quite impossible to deal with all the multitudinous activities which crowd themselves into the professional life of a busy architect, which vary more or less with every office selected for consideration, but a broad outline will be given of the general procedure in the chief matters with which practically every architect is sooner or later called upon to deal. Among other things, he will be required to advise as to the suitability of sites, and eventually to carry out the particular buildings thereon, for the following works—

- One or more private residences; residential hotels.
- Development of estate upon garden suburb lines.
- Shops—with or without dwelling accommodation.
- Shops—with or without business premises over.
- Blocks of flats, offices, garages.
- Business premises of all description.
- Places of entertainment.
- Public libraries, swimming baths, schools.
- Municipal offices.
- Factory buildings, workshops, warehouses.
- Conversion of existing premises, such as—
  - Houses into shops, flats, nursing institutions, schools.
  - Warehouse into billiard hall, etc.
- Extensions of existing buildings of all description.
- Carry out surveys and report regarding dilapidations, light and air cases, party wall awards, sanitary surveys.
- Prepare the valuation and report upon the various properties proposed to be purchased by clients, such as—
  - Private residences.
  - Shop property.
  - Factory or warehouse premises.
  - Office premises.
- Conduct arbitrations.
- Qualify for and give evidence in law cases arising out of building disputes or accidents.

Procedure

By selecting two of the foregoing items, and giving in detail the chief points for consideration, this will show not only the order of procedure, but the very considerable amount of work which has to be done, and the care and attention exercised in the preparation of a well-ordered and comprehensive report.

(*a*) ERECTING A FACTORY. Assuming a client wishes to erect a factory in a provincial town, then, in order to prepare a satisfactory report upon a proposed site, the architect would obtain information upon the following items—

- Centres of industries.
- Price of land, local rates.
- Level or evenness of site, nature of soil—
  - High or low lying.
  - Liability to floods.
- Proximity of sewers.
- Supply and price of electric power, electric light, gas power, gas light, water supply (high or low pressure, soft or hard water).
- Proximity to coal-fields—if manufacturing business.
- Proximity to steel works—if engineering business.
- Source of supplies of raw materials—if manufacturing business.
- Facilities for transport, import and export.
- Railways: Main, branch, sidings—or possibility.
- Canal or river or docks. Whether sheet piling wharfing required.
- Roads: Main, secondary, private—upkeep. Whether steep hills in vicinity.
- Possibility of outlet for effluent.
- Possibility of extension of buildings.
- Labour: Class of and supply, male and female.
- Travelling facilities for employees.
- Housing schemes, canteen, recreation ground.

(*b*) PURCHASE OF SMALL ESTATE. Assuming a client wishes to purchase a small estate with existing private residence and garage, etc., just outside the limits of administration of an urban district council, the architect must obtain information upon the following, as data upon which to construct his report—

- Situation: Surroundings, such as hills, houses, other buildings, sewage farms, gas works, asylums; shops, schools, churches, factories; sea river; water; golf, rainfall, death rate, ordnance datum, soil.
- Travelling facilities, trains, trams, buses.
- Call upon local authorities or agents regarding rating in district, road charges, electric light, gas, water, and telephone services. Local matters affecting the property.
- Check tenancies, fixtures, ancient lights—if any—rights of way, watercourse, fishing, shooting, boating.

Note plan, elevations, and dimensions for cubing, and regarding the following—

EXTERNALLY

Brick or stone facings, rough cast, half timber, weather boarding, windows—type, whether metal, wood, or both.

Roofs: tiled, slated, lead, zinc, copper, asphalt, vulcanite, ruberoid, asbestos tiling, corrugated iron, boarding, felt, battens; gutters: cast iron, zinc, asbestos; flashings: lead, zinc or cement.

Brickwork.

Chimney stacks, parapets, pointing, walls out of perpendicular, walls damp, signs of settlement.

Pavings.

Cement, blue brick, brick, tiling, tar-paving, crazy paving, forecourt, garage, and wash.

Gates, fencing, boundary walls, paths and drainage of same, gardens, garden buildings, pools and garden ornaments, trees, hedges, ditches, ponds.

Air bricks to w.c.'s and larders, ventilation under floors, damp-proof courses.

Paintwork: Wood, stone, stucco.

Drainage: Whether modern, septic tank, filter beds, cesspool.

Plan, description, size of main drain, branch drain; sewer—its position and depth, whether repairable by local authorities or private owner, outfall.

Manholes, ventilation pipes, intercepters, rendering, gullies; rain-water pipes: whether iron, zinc, asbestos; w.c. pans, traps, anti-syphonage pipes, sinks, slop-sinks, lavatory basins, water-waste preventers, bath and wastes, shower-bath and overflow water supply, cisterns and covers, ball-valves, stop-cocks.

INTERNALLY

Ceilings: Condition, plaster, compo-board, panelled, enriched, cornices, beams.

Walls: Panelling, painting, papering, tapestry, distempered.

Paintwork: Paint, enamel, graining.

Floors: Level, dry-rot, solid, hardwood, soft wood, wood block, parquet, patent jointless, tiled, tessellated, terrazzo, mosaic, skirtings.

Doors, windows, cupboards, linen cupboards, locks and fastenings.

Re-lacquering, bells—electric or otherwise—glass, sweep.

Lighting: Gas, company or own plant; electric, company or own plant.

Electric heating or power.

Cooking: Range, gas cooker, electric cooker.

Heating: Water—boiler, radiators, coils, feed cistern, pipes generally.

Gas: Radiators, gas fires.

Electric: Fires, radiators.

Coal: Stoves, range.

Hot water: Domestic boiler, sizes of pipes, circulating cylinder, calorifier, geyser, tanks.

Sanitary fittings: Bath, w.c.'s, slop sinks, sinks, shower bath, lavatory basins, traps, taps, stop-cocks, cistern and cover, sizes of service and waste pipes, overflows.

GENERALLY

Suggestions as to improvements of plan, entrances.

PRICE

Freehold.

Leasehold: Term, ground rent.

Estimated rack rent.

Restrictions, tithes, land tax.

Road widening or charges.

Town planning scheme.

Portion of estate for building development.

Procedure Out of London Area. Upon the communication to the architect of a client's intention to erect a building upon a site within the administrative area of an urban district council, the following is the outline of the procedure from the initial stages to the completion of the contract, and the occupation of the premises.

Having obtained and confirmed the receipt of the client's instructions, the architect will—

1. Make a careful survey and plot the plans of old buildings—if any exist, the site and abutments.
2. Obtain from the local authority particulars as to positions and depths of sewers and drains, and position of building line.
3. Prepare sketch plans and approximate estimate, and obtain client's approval thereto.
4. Have trial holes dug.
5. Prepare working drawings, $\frac{1}{8}$ in and $\frac{1}{2}$ in. scales. Make notes for specification during the preparation of drawings.
6. Obtain estimates from constructional engineers.
   ,, ,, ,, heating engineers.
   ,, ,, for lift.
   ,, ,, ,, lighting, sprinklers, patent flooring.
   ,, ,, ,, sanitary goods, stoves and mantles, etc.
7. Deposit copies of plans with application for permission to build and drain with the local authority.
8. Check working drawings received from specialists in item No. 6.
9. Prepare specification and form of tender; instruct quantity surveyor regarding the preparation of bill of quantities.
10. Prepare plans for and issue party wall notices.
11. Send out invitations to tender—say to selected firms.
12. Arrange for house breakers for pulling down—if any—take photographs of premises before demolition.
13. Tenders received and opened. The lowest tender examined to see that prices are run out correctly.
14. Contractor deposits his priced bill of quantities and may be given a blank copy.
15. Contracting parties sign agreement, specification, and plans.
16. Order given to commence.
17. Clerk of works appointed by architect.
18. Work to party walls, chimney stacks, etc., agreed upon with adjoining owners or their surveyors.
19. During the progress of the works—

Notebook to be kept, recording visits to job; any instructions given with dates; notes as to progress.

Orders given for any varied works to be confirmed in writing and copy supplied to quantity surveyor, so that work may be measured that will be afterwards hidden.

20. Make survey and issue interim certificates—certificate of completion.
21. Adjustment of contractor's account—contractor to produce receipted invoices, and to return all drawings.

22. At end of maintenance period make a survey and instruct contractor to make good any defects.

23. Issue final certificate for payment of retention money.

24. Obtain certificate of occupation from local authority.

Procedure in London County Council Area. Should, however, the site of the proposed building be within the area of administration of the London County Council, the whole of the foregoing items of procedure would be the same with slight modifications, together with additional requirements as follows—

Block and drainage plans and sections, with full description in writing of materials and methods of construction, are to be deposited in duplicate with the local authority for approval and permission to carry out the work.

Plans of all proposed new buildings, and alterations to existing buildings, must be deposited with the District Surveyor of the particular area for his approval before any work is begun.

There are usually some alterations, modifications, additional works or fittings necessary to put the premises into accordance with the official requirements. Every "case" is treated upon its merits and these latter conditions are very clearly set out upon the notice sent to the applicant by the superintending architect, which notice must be complied with unless alternative methods to achieve the same purposes are agreed and accepted by the Council.

Should there be any queries as to the use of special materials or details of construction not provided for in the London Building Acts, 1930 to 1939, or the London County Council's By-laws made in pursuance of these Acts, then upon the advice of the District Surveyor a special application must be made for consent to the Superintending Architect of the L.C.C. If, however, the application is disapproved, or the conditions are such that the applicant cannot accept, then he may appeal to a Tribunal of Appeal as provided for in the London Building Acts (Amendment) Act, 1939.

A list of the names and addresses of District Surveyors and their Districts is published in the R.I.B.A. Kalendar.

Party wall notices with plans showing the existing, and the proposed, work will probably have to be served on the adjoining owners, and the conditions of the award complied with.

Light and air questions may have to be contested and settled.

Details of Procedure. Arising out of the foregoing, the following need explanation—

Sketch plans.
Contract drawings.
Specification.
Bill of quantities.
Invitation to tender.
Form of tender.
Agreement and conditions of contract.
Variation orders.
Certificates.
Adjustment of accounts.
Application to local authority.
Inspection by local authority.

SKETCH PLANS. These are prepared in pencil, frequently on tracing paper and coloured sufficient for explanation only, regardless of the conventional colouring of different kinds of building materials.

CONTRACT DRAWINGS. These are usually prepared to the scale of $\frac{1}{8}$ in. to the foot together with $\frac{1}{2}$ in. details of the chief elevations. These show the complete building in plans, elevations, and sections together with a small scale block and drainage plan. Complete tracings are made and photo copies obtained, both upon linen and paper, for depositing with the local authorities and for issuing to the contractor.

SPECIFICATION. A specification is a document which explains in minute detail the whole of the work which is to be carried out, the materials and the labours upon same, together with the manner and position in which they are to be used from the commencement to the completion of the job. As far as possible this is set out in the order in which the work is to be carried out.

In addition to enumerating the materials and workmanship, certain clauses are embodied from the conditions of contract regarding time for completion, manner in which payment will be made, insurance of work and workmen, provisional sums and preliminary items regarding the commencement and carrying out of the work. The specification, when signed by the contracting parties, forms part of the contract, and is, therefore, a legal document.

BILL OF QUANTITIES. A bill of quantities is a document showing the detailed measurements of every item of work and materials embodied in the plans and specification, and when signed by the contracting parties forms part of the contract with the plans and specification.

INVITATION TO TENDER. For public work, the invitation to tender takes the form of an advertisement requesting builders to submit their names if they wish to tender.

For private work, this may be either by advertisement, similar to the above, or a formal

letter to selected builders asking whether they are willing to tender.

FORM OF TENDER. Fig. 9 shows a typical example of a form of tender in use.

AGREEMENT AND CONDITIONS OF CONTRACT. The form of contract usually adopted is the "Agreement and Schedule of Conditions for Building Contract," obtainable from the Royal Institute of British Architects, dated 1931.

F O R M O F T E N D E R

To

H. B. Pencille, Esq., A.R.I.B.A.,

Chartered Architect,

Bedford Square, London.

Sir,

We are willing to enter into a contract to carry out the whole of the work required in the erection and completion of a Detached House, Broad Avenue, Maidenhead, according to the Drawings, Specification, and Conditions prepared by you, and to your entire satisfaction for the sum of.................................. £.............

Name......................

Address...................

....

Date......................

No Tender will be considered unless this form is used and filled in and accompanied by the Specification and Drawings and delivered by 10 o'clock on.............. the...............19—.

The Employer does not bind himself to accept the lowest or any tender, nor to incur any expense in the preparation of same.

FIG. 9. FORM OF TENDER

binding by the application of a sixpenny adhesive inland revenue stamp, which must be cancelled by a signature and date; where the client is a corporation or limited liability company, it must be sealed with their official seal.

The second portion of this document is the *schedule of conditions of contract*, set out in clauses, of which the following is a summarized list—

The first portion of this document is the *agreement*, which sets out the names and addresses of the contracting parties and defines the contract drawings, specification, and quantities, which when signed form part of the contract. It states the sum of money to be paid by the employer to the contractor in consideration of his performance of the work, and also gives the name of the appointed architect. This portion is executed by the contracting parties signing, in the presence of witnesses who also sign, and the document is made legally

The works to be carried out in accordance with signed drawings and specification, and the architect's directions and explanations. Copies of all drawings, specification, and details to be supplied to contractor.

The contractor to provide everything necessary for the proper carrying out of the work.

He is to conform with any Acts of Parliament, local by-laws, and regulations relating to the work, and of any water, lighting, and any other company, and shall give all notices required by above and pay all fees.

The works are to be set out by the contractor, and the materials and workmanship to be as described in the specification.

Conditions regarding foreman, dismissal of incompetent workmen, and the appointment of clerk of works.

Variations from the drawings and payment for extras only by architect's authority.

Errors in bills of quantities and their correction. Payment for extras and omissions to be based on the original estimate.

Payment of surveyor's fees for bill of quantities.

Unfixed materials the property of the employer.

The removal of improper work and materials and reinstatement with new. Making good defects after completion of works, and conditions regarding the inspection of work already covered up.

Assignment or sub-letting only with architect's consent. Contractor to give facilities to all sub-contractors.

Liability of contractor for all damage to property and injury.

Insurance against fire.

Date of completion and damages for non-completion.

Procedure in the event of the suspension of works by contractor or by the employer.

Explanation of the terms "prime cost" and "provisional sums."

Payment to contractor and issue of certificates.

Provisions in the event of war.

Arbitration in case of any dispute arising between the contracting parties.

VARIATION ORDERS. It is provided in the conditions of contract that no orders for variations shall be valid unless received in writing from the architect, and in Fig. 10 is given the form of a typical variation order.

CERTIFICATES. The contractor is paid by the employer in instalments from time to time, in accordance with the terms stated in the conditions of contract, upon the receipt of certificates, issued by the architect, stating the sum due.

For this purpose, the Royal Institute of British Architects publish certificates in book form, a reproduction of a certificate being given in Fig. 11.

The certificate, when duly filled in, is sent with a covering letter to the contractor, who in due course forwards it to the employer and upon receipt of payment sends the formal contractor's receipt to the employer. At the time of sending the certificate to the contractor, it is usual to notify the employer in writing.

Bedford Square,
London, W.C.2.
3rd February, 19—.

Messrs. Thoroughgood & Co.,
Building Contractors,
Slough.

Dear Sirs,

HOUSE, BROAD AVENUE, MAIDENHEAD

VARIATION ORDER NO. 1--EXTRA.

I have the pleasure to confirm verbal instructions given on the job to-day for the following extra works to be carried out--

Form pit in garage in accordance with estimate dated 14th January last at a cost of £15-12-6.

Lay 1" oak wood-block flooring in Hall in lieu of 1½" G. & T. flooring at an additional cost of £10-8-0.

Yours faithfully,

H. B. PENCILLE.

FIG. 10. VARIATION ORDER

ADJUSTMENT OF ACCOUNTS. An outline is now given of the procedure by the architect in the adjustment of a contractor's account at the completion of a contract where there were no quantities. Upon the receipt of the contractor's detailed account, which should be accompanied by receipted bills, the architect would—

1. Go through the specification and prepare an abstract of all the provisional sums and p.c. items.
2. Go through the specification, noting items added, omitted or varied, and check with the variation orders.
3. Compare the signed contract drainwgs with the office copies of drawings, and note items added, omitted or varied, and check with the "variation" orders.

4. Peruse the letters sent to the builder, noting anything which may affect the account.
5. Peruse all letters from the builder and check as in No. 4.
6. Peruse the letters sent to and received from client and extract items as in No. 4.
7. Peruse the job notebooks kept, showing the progress of the work and extract items as in No. 4.
8. Prepare a schedule of "variation" orders issued under "extras" and "omissions."
9. Prepare a schedule of specialists' and sub contractors' estimates which were excepted.
10. Ascertain whether the accounts have been paid for all provisional sums and p.c. items, such as steelwork, lifts, electrical work, stoves and mantels, sanitary goods, heating, district surveyor's fees, etc.
11. Agree or adjust every item in the account one by one; carry the amount of the omission or addition in each item to a schedule under each head; and finally carry the totals to the summary of account, an example of which is shown in the next column.
12. Obtain all the drawings and specifications from the builder with which he was provided for the execution of the contract.
13. Issue the certificate of completion.
14. Note any necessary reparations and making good to be done at the termination of the maintenance period —and agree these with client.

Amount of Contract (as per Tender dated) .		£
To Additions	£	
By Omissions	£	
		£
Paid on Account (as per Cert. No.)		£
Add Surveyor's Fees—		
$2\frac{1}{2}\%$ on £—	£	
$1\frac{1}{2}\%$ on £—	£	
	£	
Less Amount of Retention (as per Certificate of Completion No.)		£

15. See that these several works are satisfactorily completed.
16. Issue final certificate for payment of retention money.

APPLICATION TO LOCAL AUTHORITY. It is provided under the by-laws that every person intending to erect a building shall give due notice

Architect's Address
Date

Certificate No.------

Previous Instalments £......

Present Instalment £......

Total to date £......

I HEREBY CERTIFY that the sum of...............

is due to.....................of......................

on account of Works at................................

under the terms of the Contract therein dated.......19...

£.........

....
Chartered Architect.

To...................

....

CONTRACTOR'S RECEIPT.

...............19...

Received from...

the sum of £...........................in payment of

Certificate No.....dated...............19...

£................

Stamp.

FIG. 11. ARCHITECT'S CERTIFICATE

to the local authority in writing, accompanied by complete plans and sections of every floor on tracing cloth to a scale of not less than ⅛ in. to 1 ft., showing the position of all drains, water-closets, and all sanitary appurtenances.

This must be accompanied by a written description of the materials to be used in the construction of the building and drainage, and state the means of water supply. At the same time a block plan must be deposited, drawn to a scale of not less than 44 ft. to 1 in., showing the position of the proposed building and the buildings immediately adjoining the width and level of the street, the relation of yard and lowest floor to the level of the road; also the lines of drainage, with size, depth, and inclination of each drain and method of ventilating the drains.

For the above purpose, the local authority provide application forms with all the items enumerated, and the forms require only to be filled in, signed, and deposited.

INSPECTION BY LOCAL AUTHORITY. The plans and application for the proposed building having been duly deposited and approved by the council, a formal approval is sent to this effect by the council surveyor to the architect; this approval is accompanied by building notices, which must be sent in by the builder from time to time—as hereunder enumerated—notifying the surveyor that the work is ready for inspection.

The work must be inspected and approved by the building inspector at the following stages before the next stage is proceeded with—

When trenches are excavated.
When foundation concrete is in.
When damp-proof course is laid.
When drains are laid.
At completion of the building.

The building inspector attends during the testing of the drains and sanitary appliances; and upon the whole of the work being completed to his satisfaction, a certificate of occupation is issued by the clerk to the council. This certificate states that the drainage has been completed to the satisfaction of the surveyor to the council, and the premises are fit for occupation.

ARCHITECT'S RELATIONS WITH OTHER PERSONS

There are a number of persons other than the builder who enter into the "field of action" in the matter of carrying out a building contract; their relationship with the architect is here outlined.

Consulting Engineer. Many architects have neither the time, inclination, nor, possibly, the qualifications to prepare a comprehensive design, with all the accompanying calculations for a steel-framed building of anything above a very moderate-sized structure, and for this purpose the services of a consulting engineer are retained.

He is engaged by the architect with the approval and sanction of the client; and his fees, which are in addition to the architect's fees, are paid by the client through the architect.

The consultant prepares the scheme for the constructional steelwork from the general plans of the building supplied by the architect; obtains competitive tenders from structional engineers; advises upon the acceptance of one of these; supervises the erection; notifies the architect from time to time respecting the amounts to be certified for payment; and takes the responsibility for the efficient design and execution of this section of the work.

Quantity Surveyor. In the provinces it is quite the usual practice for the architect to prepare the bill of quantities for the purpose of obtaining uniform tenders, and the clients are cognizant of this method. But in London it is the more general practice for a quantity surveyor to be appointed for this purpose. In fact, one of the regulations of the London Master Builders' Association states that its members are requested not to submit tenders for work estimated to cost over £1,000 unless quantities are provided, except in the case of alterations, or where not more than three builders are invited to tender.

A quantity surveyor is appointed by the architect, with the permission, and acting on behalf, of the client.

The quantity surveyor's fees are provided for in the bill of quantities, and are payable by the builder upon receipt of the architect's certificate including the amount.

The quantity surveyor receives instructions from the architect, and has no authority to give orders to the builder regarding the work or variations. He prepares the bill of quantities from the architect's drawings and specification, also the form of tender, and checks the tenders. He prepares statements from time to time, showing the value of work executed, and the amount to be certified for payment by the architect to the contractor and sub-contractors.

He checks the builder's estimates of the cost of variations as they occur, and upon receipt of the builder's account, he prepares the final statements.

Clerk of Works. Where the size, or importance, of a job necessitates constant supervision, this is obtained by appointing a clerk of works, who acts as a permanent representative of the architect. The client's permission for this must first be obtained, and the rate of payment agreed.

The clerk of works is usually selected and appointed by the architect, and paid by the client, either direct or through the architect.

He receives all his instructions from the architect, to whom he is responsible; he may give ordinary directions to the builder, who may appeal to the architect should he consider the directions unreasonable.

Clients. Advertising by architects in this country as a means of obtaining work is not permissible, and in the suggestions governing the professional conduct and practice of architects, drawn up by the Royal Institute of British Architects, it is stated that: "An architect must not publicly advertise nor offer his services by means of circulars. He may, however, publish illustrations or descriptions of his work and exhibit his name on buildings in course of execution (providing it is done in an unostentatious manner) and may sign them when completed."

This being the case, an architect obtains his work from sources other than advertising, and it may be secured from: (*a*) friends; (*b*) recommendation by former clients; (*c*) other architects; (*d*) solicitors whose special work involves dealing with property and conveyance; (*e*) name exhibited on work in progress; (*f*) obtaining "internal information" in various ways of projected building schemes; (*g*) architectural competition.

The "client" may be, for example, a public body, a board of directors of a limited company, the principals of a firm, a building committee, or a single individual.

The appointment of the architect by a client, and the instructions to proceed, should be in one or other of the following forms—

If the client is a *public body*, or a *board of directors* of a limited company, it is necessary for the architect to receive a letter formally appointing him, which letter, in order to be valid, should have the seal of the corporation or company. The formal instructions should be contained in an excerpt from the minutes of the directors' meeting, and signed by the secretary.

If the client be the *principals of a firm*, the instructions should be contained in a letter, signed in the ordinary business manner. If the client be a *committee*, the instructions would be conveyed in a copy of a minute of meeting, as in the first case, and signed by the chairman. Finally, if the client is an *individual*, the instructions may be either by letter or given orally; but in the latter case it is always advisable for the architect to confirm the instructions in writing, the acceptance of which letter by the client is sufficient evidence of concurrence.

In all cases it is well to obtain the client's signature as a note of approval on the sketch plans before proceeding with the finished drawings, as in the unfortunate event of the client repudiating responsibility this will give the necessary evidence of instructions required in a court of law.

When an architect first discusses with a client a building scheme, for example for a factory, it is essential for him to get a clear understanding regarding the arrival and storage of the raw material, the processes and supervision of manufacture, the storage of accessories and tools, the packing and dispatch of the finished products, and information regarding the number, designation and accommodation of the administrative staff, and also of the working staff.

Similarly, when an architect receives instructions from a client regarding a proposed residence, it is imperative that he should obtain the fullest information, preferably by visiting, as to the social position and activities of the home life of the client, in order that a really satisfactory design should be evolved, giving the greatest amount of comfort to the occupants with the least amount of labour to the domestic staff.

Chapter III—PROFESSIONAL CONDUCT AND PRACTICE

The Royal Institute of British Architects has drawn up and published in the R.I.B.A. Kalendar a code of professional practice of architects; this publication records, in ten clauses, which might be described colloquially as the Ten Commandments of the Architectural Profession, the practice of architects and indicates a standard of conduct to be adhered to by its members, and of which the following is a précis—

A member of the R.I.B.A. is governed by the Charter and By-laws of the Royal Institute. The clauses indicate in a general way the standard of conduct to which members of the R.I.B.A. must adhere, failing which the Council may judge a member guilty of unprofessional conduct and either reprimand, suspend or expel him or her.

1. An Architect is remunerated solely by his professional fees and he should uphold in every way possible the Scale of Professional Charges adopted by the Royal Institute.
2. An Architect must not accept any work which involves the giving or receiving of discounts or commissions.
   An Architect may be architectural consultant, adviser or assistant to building Contractors, decorators or other firms or companies under certain specified conditions.
   An Architect may be a director of any Company under certain specified conditions. His name and affix may appear on the notepaper of the Company.
3. An Architect must not advertise nor offer his services by means of circulars or otherwise. Under certain specified conditions there is no objection to an Architect
   (i) allowing signed illustrations and descriptions of his work to be published in the Press;
   (ii) signing his buildings;
   (iii) exhibiting his name outside his office and on buildings in course of construction, alteration and/or extension.
   Auctioneering and House Agency are inconsistent and must not form part of the practice of an Architect.
4. An Architect must not attempt to supplant another Architect, nor must he compete by means of a reduction of fees or by other inducement.
5. An Architect, on being approached to proceed with professional work upon which another Architect was previously employed, shall notify the fact to such Architect.
6. In all cases of dispute between Employer and Contractor the Architect must act in an impartial manner.
7. An Architect must not permit any payment to be made to him by the Contractor, whatever may be the consideration, unless with the full knowledge and approval of his client.
8. An Architect should not take part in a competition as to which the preliminary warning of the Royal Institute has been issued and must not take any part in a competition as to which the Council of the Royal Institute shall have declared by a Resolution that members must not take part.
9. An Architect must not act as Architect or Joint Architect for a work which has been the subject of a competition in which he was an Assessor.
10. Where an Architect takes out the Quantities for his buildings, it is desirable that he should be paid directly by the Client and not through the Contractor, except with the previous consent of the Client.

It has been established that the architect, from the time he receives instructions from a client up to the time of signing a building contract, is acting as an agent for and on behalf of his client, and is in duty bound to do his utmost for the client in all matters; but after the contract is signed, he is in the position of a quasi-arbitrator, and must use his endeavours and authority both in the interests of the client and of the contractor, to see that they are dealt with in a fair and impartial manner each to each.

In all dealings with his clients, the architect must of necessity exercise a great amount of tact, judgment, and patience; but although any one of these may be required in a greater or less degree, even as one client differs from another, the amount of carefulness, exactitude, and perspicuity exercised must never vary, but be maintained at the highest degree.

Professional Charges. The Royal Institute of British Architects have drawn up and published a very careful and detailed (*a*) Scale of Professional Charges and Conditions of Engagement; (*b*) Scale of Architects' Charges for Local Authorities and Public Utility Societies Housing Work; (*c*) Scale of Architects' Fees for Speculative Builders' Work; any of which may be obtained for a few pence from the Royal Institute. It is felt, therefore, to be unnecessary to reproduce these *in extenso*, but an extract from the R.I.B.A.'s little handbook entitled, *The Architect and His Work*, dealing with "the architect's fees," is reproduced—

"The basis of an architect's remuneration is as detailed in the Scale of Professional Charges

issued by the Royal Institute of British Architects."

According to this scale, payment is calculated by means of a percentage on cost—for new works involving an expenditure of £2,000 and over, the payment is 6 per cent, and for smaller works payment is on a scale graduated up to 10 per cent, where only £100 is expended. Where the work involves alterations to existing buildings, a higher percentage may be charged, not exceeding twice the foregoing percentages.

These charges do not apply to services rendered in connection with negotiations regarding party walls, rights of light, and legal matters generally, nor do they apply to work of a purely decorative character—the charges for these services are dependent on the work involved, and are usually settled by arrangement and mutual agreement.

It is often pertinently suggested that since an architect's duty consists, among other things, in seeing that his client's money is not wasted, it is illogical to remunerate him on a system which makes the fees rise in direct ratio with the outlay. This illogicality is admitted, and also objected to, by architects as well as by their paymasters, for it sometimes seems hard on an architect to be robbed of £60 every time he by some ingenuity of plan, or construction, saves his employer £1,000. But the system prevails because it does rough justice to all parties, insomuch as it is reasonable in a general way that the designer of a £10,000 building, should be paid twice as much as the architect of one costing £5,000.

When bills of quantities are necessary, it is customary for the architect to advise the client on the choice of a quantity surveyor. The surveyor's fees are customarily added as a percentage to the bill of each separate trade, and paid as part of the payment to the builder. It will generally be found that this apparently additional payment is more than met by the saving effected in the regulation of the accounts which the surveyor's work affords.

Architectural Competitions. It has been mentioned previously that architectural competitions provide a means for an architect to obtain commissions, and there have been outstanding examples where almost unheard of, but capable men, have risen from obscurity into fame in a single stride by winning the competition for, and carrying out, some large and important public building.

An explanatory memorandum on the system of architectural competitions published in the R.I.B.A. Kalendar states—

> The system of architectural competitions has been recognized for many years as the best method of obtaining designs for, and architects to supervise the erection of, all buildings, particularly where the expenditure of public funds is involved.
>
> For a modest expenditure which represents a very small proportion of the cost of the building the promoters can obtain designs from competent architects in all parts of the country. If the competition is properly organized in accordance with established practice there can be no question but that the building promoters will benefit from the concentrated study of a large number of architects, all of whom will submit differing solutions of the problem.
>
> During many years' experience in the conduct of architectural competitions the R.I.B.A., representing the great majority of the practising architects in the country, has built up a series of Regulations governing the Promotion and Conduct of Architectural Competitions which are recognized as most satisfactory and equitable to all concerned, and have been used as a model in other countries.
>
> These regulations are published in pamphlet form, the outlines of which are as follows—
>
> (*a*) The nomination of an Assessor or Assessors who shall be Architects of acknowledged standing.
>
> (*b*) Each design shall be accompanied by a declaration, stating that the design is the competitor's own personal work. A successful competitor must satisfy the Assessor that he is the *bona fide* author of the design submitted.
>
> (*c*) No Promoter of a competition, and no Assessor engaged upon it, shall compete or assist a competitor or act as Architect for the proposed work.
>
> (*d*) The premiums shall be paid in accordance with the Assessor's award, and the author of the design placed first by the Assessor shall be employed to carry out the work.
>
> (*e*) Procedure and payments to the author of the selected design in the event of no instructions being given for the work to be carried out.
>
> (*f*) Payment of fees to the selected Architect.

Then follows advice to the Promoters of an intended competition regarding the appointment of one or more Assessors and as to remuneration for their services, detailed particulars of the duties of an Assessor and alternative methods in which competitions may be conducted; concluding with a rider that the Council or the President of the R.I.B.A. shall be entitled to sanction an exception to the regulations where, in their or his view, the interests of the Promoter and the best interests of the profession clearly justify this course.

Architectural Education. It has been definitely established by those most competent to judge, that the one-time method of training for entry into the architectural profession, by means of the articled system, was not so comprehensively sound and thoroughly efficient as is the modern

method of education in architectural schools approved by the R.I.B.A.

A list of these approved schools is published in the R.I.B.A. Kalendar. The curriculum and the length of the complete course of studies varies at these schools, but an R.I.B.A. Board of Architectural Education, representative of the architectural, building and academic professions, deals with the whole of the Institute's examinations and supervises the educational programmes of these "recognized" schools.

Students of these schools, upon passing the examinations and gaining a diploma, obtain exemption from the R.I.B.A. Intermediate and Final examinations.

Registration of Architects. The profession of architecture is "closed" and the registration of architects in the United Kingdom is regulated by the Architects Registration Acts, 1931 to 1938.

Under the 1938 Act registration is compulsory. No person may practise or carry on business under any name, style or title containing the word "Architect" unless he has been registered. The use of the title "Architect" by an unregistered person will render him liable to a fine not exceeding £50 and a further fine not exceeding £10 for every day on which the offence continues after conviction.

The following are the qualifications for registration set out in the 1931 Act—

That the applicant

(1) is a member of the Royal Academy or the Royal Scottish Academy, or

(2) has passed an examination in architecture which is for the time being recognized by the Council, or

(3) possesses such other qualification as may be prescribed by the Council by Regulations approved by the Privy Council.

The following examinations are recognized by the Council as a qualification for registration under paragraph (2) above—

The Royal Institute of British Architects: Final Examination, Special Final Examination.

The Aberdeen School of Architecture, Robert Gordon's Technical College, Aberdeen: Diploma Final Examination.

The Birmingham School of Architecture, Central School of Arts & Crafts, Birmingham: Diploma Final Examination.

The Welsh School of Architecture, The Technical College, Cardiff: Diploma Examination.

School of Architecture, University College, Dublin (National University of Ireland): The Final Examination for the Degree of Bachelor of Architecture.

The School of Architecture, Edinburgh College of Art: Diploma Final Examination.

The Glasgow School of Architecture: Diploma Final Examination, University of Glasgow Degree of Bachelor of Science in Architecture Final Examination.

The School of Architecture, Leeds College of Art: Diploma Examination.

The Liverpool School of Architecture, University of Liverpool: Final Examination for the Degree of Bachelor of Architecture, Final Examination for the Diploma in Architecture.

The School of Architecture, The Architectural Association, London: Diploma Final Examination.

The Bartlett School of Architecture, University of London: Final Examination for the Degree of Bachelor of Arts in Architecture, Final Examination for the Diploma in Architecture.

The School of Architecture, University of Manchester: Bachelor of Arts degree with Honours in Architecture Final Examination, Certificate Final Examination.

The Department of Architecture, University of Sheffield: Degree of B.A. with Honours in Architecture Final Examination, Diploma Final Examination.

The School of Architecture, King's College (University of Durham), Newcastle-upon-Tyne: Degree of B.Arch. Final Examination, Diploma in Architecture Final Examination.

The Polytechnic, Regent Street, London: The Diploma Final Examination of the School of Architecture.

Department of Architecture, The Northern Polytechnic, Holloway, London: Diploma Final Examination.

NOTE. It is desired to acknowledge indebtedness to the Royal Institute of British Architects for permission to give extracts from their various publications in this article.

Structural Engineering

By W. ARNOLD GREEN, M.A., B.Sc., A.M.Inst.C.E., M.I.Struct.E.
Revised by NEWMAN TATE, M.I.Mech.E., M.I.Struct.E., M.I.Loco.E.

Chapter I—FORCES ACTING ON A STRUCTURE

ALTHOUGH the term "Structural Engineering" is applicable equally to the building of a sand castle, an Egyptian pyramid, a Forth bridge, an Eiffel tower, and a wasps' nest, it is proposed in this section to deal with only a small part of what is commonly known as "building construction"; the principles, however, underlying the right use of materials in making a safe structure are the same whatever the structure and whatever the materials used.

Structures designed to deal with mass in motion are in the province of the mechanical engineer, and though it is impossible to draw a hard and fast line between structural and mechanical engineering, this section will be mainly concerned with *statics*, which may be defined as "that branch of dynamics which treats of the properties and relations of forces in equilibrium, the body upon which they act being at rest."

At all points in such structures there must be *equilibrium*, i.e. a complete balance of forces, as otherwise there would be movement. This balance must be maintained for the structure as a whole as well as for the individual parts. Thus the sum of the loads on and of the structure must exactly equal the sum of the reactions from the supports to the structure. This will ensure that there will be no movement of position; but to ensure also that there will be no movement of rotation a further condition must be satisfied. This condition may be expressed as follows: the tendency of the loads on and of a structure to cause rotation about any point must be exactly balanced by the tendency of the reactions from the supports to the structure, to cause an equal rotation about the same point in the opposite direction. This is generally expressed—

Sum of horizontal forces = 0.

Sum of vertical forces = 0.

Sum of moments of forces about any point = 0.

It should be noted that the term "support" may be regarded as relative. Any point of a structure may be regarded as the support to the adjacent portion, and the above-mentioned conditions of equilibrium must be satisfied.

Forces Acting on a Beam. To illustrate by an example, consider a beam of length l and weight w per unit length, supported at two points R_1 and R_2, and carrying two point loads of known weight W_1 and W_2 in the position shown in Fig. 1.

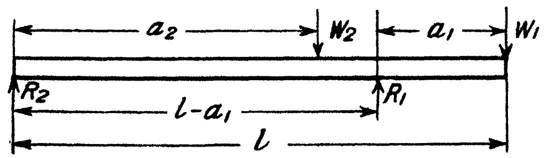


FIG. 1

It should be remarked that in practice there must be an appreciable bearing width both for the loads and the reactions, but at the moment, for simplicity, they are considered as acting at points.

The total weight of the beam, i.e. the weight of the structure itself, equals $w \times l$. The total load on the structure equals $W_1 + W_2$. The total reaction from the supports to the structure is the sum of the reactions from points R_1 and R_2, which may be similarly termed R_1 and R_2 respectively.

As the sum of the loads of and on the structure must equal the sum of the reactions from the supports to the structure, it follows that—

$$w \cdot l + W_1 + W_2 = R_1 + R_2 \qquad (1)$$

Moments of Forces. The *moment* of a force about a point, or the tendency of the force to cause rotation about that point, is proportional both to the force and its *lever arm*, i.e. the distance of the line of action of the force from the point.

The moment of a force about a point is thus expressed as *the product of the amount of the force and the lever arm.*

Thus the moment of W_1 about R_2 equals $W_1 \cdot l$, and the moment of W_2 about the same point equals $W_2 \cdot a_2$.

The lever arm of the weight of the structure itself is the distance of its centre of gravity from R_2. The moment of the weight of the structure itself about R_2 is therefore—

$$w \times l \times \frac{l}{2} = \frac{w \cdot l^2}{2}$$

These moments tend to produce clockwise rotation about R_2. The resisting counter-clockwise rotation about R_2, due to the reactions R_1 and R_2, equals $R_1 \cdot (l - a_1) + R_2 \cdot O = R_1 \cdot (l - a_1)$. Equating the clockwise moment to the counter-clockwise moment—

$$W_1 \cdot l + W_2 \cdot a_2 + \frac{w \cdot l^2}{2} = R_1 \cdot (l - a_1) \quad (2)$$

from which the unknown reaction R_1 is immediately deducible, and hence R_2 from (1).

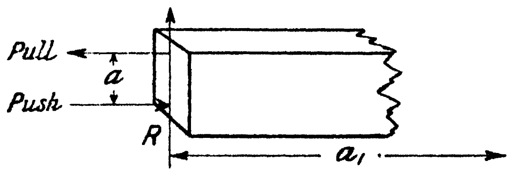


FIG. 2

The left-hand side of (2) may be written $(W_1 + W_2 + w \cdot l) \cdot a_3$, where a_3 is the distance from R_2 of the centre of gravity of the weights on and of the structure. Thus—

$$(W_1 + W_2 + w \cdot l) \cdot a_3 = R_1 \cdot (l - a_1)$$

or

$$(R_1 + R_2) \cdot a_3 = R_1 \cdot (l - a_1) \quad (3)$$

If a_3 is less than $l - a_1$, R_1 is obviously less than $R_1 + R_2$, so that R_2 will be of the same sign as R_1, i.e. both reactions are upward.

If a_3 is greater than $l - a_1$, owing to the relatively great weight of W_1, then R_1 will be greater than $R_1 + R_2$, and R_2 will be of the opposite sign to R_1, i.e. it will act in the opposite direction to R_1, and serve as an anchorage to prevent the beam rotating in a clockwise direction about R_1.

The same results could have been deduced by taking rotation moments about any other point, but by choosing a reaction point as the assumed centre of rotation (or fulcrum) the value of that reaction is eliminated from the resulting equation of moments.

Balancing or Resisting Moment. Consider now the cantilever portion of Fig. 1. Fig. 2 shows a "close up" of the end of this at R_1. More information is given in Chapter IV, to which the reader should refer.

The forces acting on the overhanging portion, to the right of the section. are W_1, a distance a_1 away and the weight of the beam $w.a_1$, acting at its centre of gravity a distance $a_1 \div 2$ from the section.

The support for this overhanging portion is the vertical face of the remaining beam, to the left of the imaginary section. This vertical face must provide a vertical reaction R equally $W_1 + w.a_1$. It must also provide reactions to produce a counter-clockwise moment balancing the clockwise moment $(W_1 \cdot a_1 + \frac{w \cdot a_1^2}{2})$, due to the load on and of the structure.

A horizontal pull on the top portion of the section, and a horizontal push on the bottom portion, will produce this balancing moment.

As there is no horizontal force acting on the cantilever, the pull and push must be equal. If this pull and push is denoted by P, and the distance between their centres of action by a, then $P \cdot a = W_1 a_1 + \frac{W \cdot a_1^2}{2}$.

The method of determining P and a will be discussed later.

A further and important condition that must be satisfied, if movement towards the ground is to be avoided, is that all members composing the structure, and the joints connecting them, must be adequate for all loads coming on them.

Chapter II—LOADS ON STRUCTURES

Materials of Construction. The number of materials available for the use of the structural engineer is yearly increasing. The use of stone and timber was probably known to man in his remotest savage state. The employment of metals for general building construction was made practicable by the introduction of rolling mills, one for sheet-iron being first used in 1728, though it was not till 1783 that Cort, the inventor of the puddling process for converting pig-iron into malleable metal, produced iron bars by means of grooved rolls.

To the introduction between 1860 and 1870 of the manufacture of mild steel, by the Bessemer and open-hearth processes, the present extensive use of structural steel is mainly due.

Bricks, at first sun-baked and later produced in kilns, are of remote antiquity. The use of lime for mortar and for concrete was known to the Romans, but it was not till a century ago that the invention of Portland cement made possible the extraordinary growth in the use of concrete and reinforced concrete that is being witnessed to-day.

Structural materials may be classified under three heads—timber, masonry, and metals.

Before attempting to describe the properties of structural materials, it is necessary to have some idea of what properties concern the structural engineer, so beyond the matter of weight, which is dealt with in Table III, further detailed description of structural materials is postponed.

Live and Dead Loads. The designer of a structure often has to work to regulations which specify the loads to be used in the calculations, as *live loads* to be added to the *dead load* of the structure and finishes. These loads may often appear to be excessive. Thus a particular schoolroom floor with desks may never be called upon to support a load of people averaging more than 20 lb. per sq. ft. of floor area, but it should be remembered that during construction, floors are often loaded with building materials more severely than they would ultimately be even if he design load were realized.

The Steel Structures Research Committee of the Department of Scientific and Industrial Research made a careful investigation into this question of loading, and published their findings in their first Report (1931). A recommended Code of Practice is embodied in the Report and has been adopted by the London County Council with slight modifications as minimum

TABLE I

SUPERIMPOSED LOADS ON FLOORS AND ROOFS AS EQUIVALENT DEAD LOADS SPECIFIED IN B.S.S. 449

	Lb. per sq. ft. of Floor Area, excluding allowance for Partitions
Rooms used for domestic purposes, hotel bedrooms, hospital rooms and wards	40
Offices, floors above entrance floor	50
Offices, entrance floor and floors below entrance floor	80
Churches, schools, reading-rooms, art galleries, and similar uses	70
Retail-shops and garages for cars of not more than 2 tons dead weight	80
Assembly halls, drill halls, dance halls, gymnasia, light workshops, public spaces in hotels and hospitals, staircases and landings, theatres, cinemas, restaurants, and grand-stands	100
Warehouses, book, and stationery stores and similar premises, together with garages for motor vehicles exceeding two tons dead weight	Actual load to be calculated, but not less than 200.

	Lb. per sq. ft. of covered area
Flat roofs and roofs inclined at an angle with the horizontal of not more than 20°	30

On roofs inclined at an angle with the horizontal of more than 20° a minimum superimposed load (deemed to include the wind load) of 15 lb. per sq. ft. of surface shall be assumed acting normal to the surface, inwards on the windward side, and 10 lb. per sq. ft. of surface similarly acting outwards on the leeward side, provided that this requirement shall apply only in the design of the roof structure.

requirements for buildings of normal type when relief is asked by designers from the more conservative provisions of the London Building Act of 1930.

The British Standards Institution has based the British Standard Specification for the use of Structural Steel in Building (No. 449–1937) on this code, and frequent reference will be made to B.S.S. 449 in what follows.

In warehouses it is sometimes possible to form a close estimate of the actual loads the floors will have to carry, but often the choice of a suitable design load is bound to be a guess in the dark aided by experience, the designer being supported by the consciousness of margins of safety necessitated by ignorance.

Weights of Materials. The approximate weights, shown in Table II, of stores per cubic foot, are given in the Carnegie Steel Co.'s handbook. Knowing the probable height of the pile or stack, the suitable design load can be readily obtained by multiplying height and weight.

Most engineering handbooks give tables of specific gravities and weights per cubic foot of various substances. The latter is not necessarily $62\frac{1}{2}$ times the former, as a cubic foot of coals or stones, for instance, contains varying amounts of air space. Nor does it necessarily follow that a cubic foot of damp material is heavier than a cubic foot of the same material dry, as the greater cohesion of the damp material may result in a greater amount of air space more than compensating for the additional weight of water.

The lists of weights, given in Table III, are taken from R. A. Skelton & Co.'s Handbook, No. 16. The values given are rough averages, the weights of many substances showing

TABLE II

APPROXIMATE WEIGHTS OF STORES

In Lb. per Cubic Foot of Space Occupied

Building Materials	
Cement, Natural	59
Cement, Portland	73
Lime and Plaster	53
Groceries and Wines	
Beans, in bags	40
Canned Goods, in cases	58
Coffee, Roasted, in bags	33
Coffee, Green, in bags	39
Dates, in cases	55
Figs, in cases	74
Flour, in barrels	40
Rice, in bags	58
Soda, in barrels	46
Salt, in bags	70
Soap Powder, in cases	38
Starch, in barrels	25
Sugar, in barrels	43
Sugar, in cases	51
Tea, in chests	25
Treacle, in barrels	48
Wines and Liquors, in barrels	38
Drugs, Paints, etc.	
Alum, Pearl, in barrels	33
Blue Vitriol, in barrels	45
Glycerine, in cases	52
Linseed Oil, in barrels	36
Linseed Oil, in iron drums	45
Red Lead and Lithage, dry	132
Rosin, in barrels	48
Shellac, Gum	38
Soda, Caustic, in iron drums	88
Soda, Silicate, in barrels	53
Sulphuric Acid	60
White Lead Paste, in cans	174
White Lead, dry	86
Hardware	
Hinges	64
Locks, in cases, packed	31
Sash Fasteners	48
Screws	101
Sheet Tin, in boxes	278
Wire, Insulated Copper, in coils	63
Wire, Galvanized Iron, in coils	74
Textiles, etc.	
Cotton, in bales, compressed	18
Cotton, Bleached Goods, in cases	28
Cotton, Flannel, in cases	12
Cotton, Sheeting, in cases	23
Cotton Yarn, in cases	25
Hemp, Italian, compressed	22
Hemp, Manila, compressed	30
Jute, compressed	41
Linen, Damask, in cases	50
Linen Goods, in cases	30
Linen Towels, in cases	40
Tow, compressed	29
Wool, in bales, compressed	48
Wool, not compressed	13
Wool, Worsted, in cases	27
Miscellaneous	
Glass and Chinaware, in crates	40
Hides and Leather, in bales	20
Hides and Leather, in bundles	37
Paper, Newspapers, and Strawboards	35
Paper, Writing and Calendered	60
Rope, in coils	32

considerable variation ; thus a cubic foot of one sample of granite may weigh as much as 187 lb. per cub. ft., and another sample as little as 162 lb. The weight of porous materials and of timber varies with the moisture content. The approximate weights of roofing materials are given in Table IV.

Concentrated Loads. A beam carrying only a small floor area may be called upon to bear a concentrated weight much greater than the product of the floor area and the design load. To guard against this contingency, every beam (except closely spaced floor beams, which will share with their neighbours any concentrated load above one of them) should be strong enough to carry the greatest concentrated load likely to come on to it. B.S.S. 499 specifies that floors must be capable of carrying in any position the following concentrated loads as an alternative loading to the superimposed loads given in Table I.

	Alternative Concentrated Load
Entrance floors and floors below the entrance floors of office buildings	2 tons
Garage or other floors for motor vehicles exceeding 2 tons dead weight	1·5 × maximum wheel load, but not less than 1 ton
Other floors (except those for an applied load of 40 lb. per sq. ft.)	1 ton
Floors or flat roofs for an applied load of 40 lb. per sq. ft. or less .	½ ton

The above alternative concentrated loads may be considered in each case as equally distributed over a floor area of 2 ft. 6 in. square.

In the case of floor beams entirely embedded in concrete and spaced not wider than 3 ft. centre to centre, the concentrated load may be regarded as borne equally between two beams.

The above alternative loads need not be considered, however, in calculating loads on columns and foundations.

Impact. Design loads are treated as stationary loads, which should include an allowance for impact, when moving loads or machinery with reciprocating parts are to be carried.

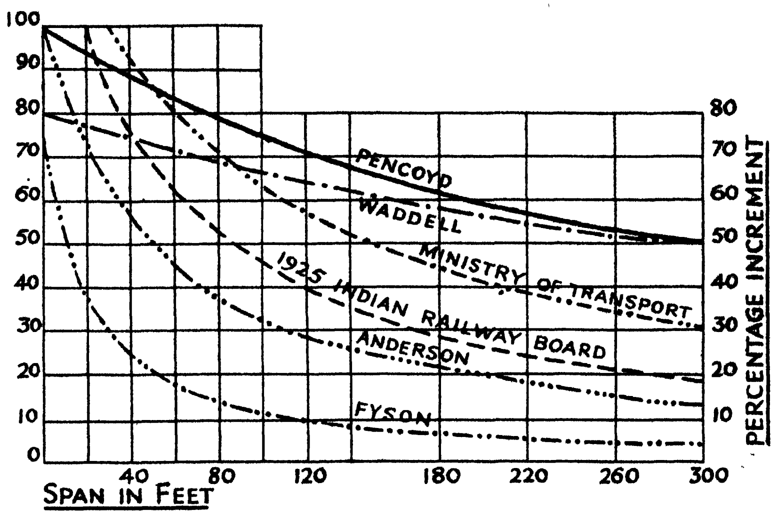


FIG. 2A

A great divergence of opinion exists as to what percentage addition to the actual weight of the moving load is suitable.

For highway bridges the Ministry of Transport specifies a 50 per cent addition to the assumed total weights of traction engine and trucks. The chart, Fig. 2A, shows various formulas used for finding the value to be used for impact on railway bridges.

For crane runways 50 per cent or even 100 per cent is sometimes asked for, but in view of the fact that the cranes themselves are often designed for an impact of only 10 per cent of the load lifted, 20 per cent of the wheel load is probably a sufficient impact allowance.

The impact effect due to the rapid starting or stopping of a loaded lift-cage will depend on the rate of acceleration (or retardation). The lift makers usually specify the equivalent dead loads to be used in designing the supports for the lift machinery.

For a crowded staircase 100 lb. per sq. ft. should be a sufficiently large design load, but the staircase should be strong enough not to collapse under the load of the heaviest furniture (e.g. an office safe) which may come upon it.

TABLE III

WEIGHTS IN POUNDS PER CUBIC FOOT

	lb.
Liquids	
Acid, Hydrochloric 40%	75
Acid, Nitric 91%	94
Acid, Sulphuric 87%	112
Alcohol	49
Benzine	46
Gasoline	42
Mercury	849
Oils	58
Paraffin	56
Petrol	55
Petrol, Refined	50
Water, Fresh	62
Water, Salt	64
Metals	
Aluminium	165
Brass	520
Bronze	510
Copper	550
Gold	1205
Gun-metal	540
Iron, Cast	450
Iron, Wrought	480
Lead	710
Nickel	530
Platinum	1342
Silver	655
Steel	490
Tin	460
White-metal	460
Zinc	440
Soils, etc.	
Chalk	170
Clay	135
Earth, Loose	75
Gravel	110
Mud, Dry	100
Mud, Wet	120
Sand, Dry Loose	100
Sand, Wet	130
Shale	160
Stones, Masonry, Aggregates, etc.	
Brick, Pressed	150
Brick, Common	125
Brick, Soft	100
Brickwork	112
Cement	90
Concrete	140
Concrete, Reinforced	150
Concrete, Coke Breeze	90
Flint	160
Granite	170
Lime	60
Lime Mortar	105
Limestone, Compressed	170
Limestone, Granular	125
Limestone, Loose Broken	95
Limestone Walls	165
Marble	170
Plaster of Paris (Gypsum)	140
Rubble Masonry	140
Sandstone	150
Sandstone Masonry	140
Slate	175
Timber	
Ash	50
Beech	50
Cedar	35
Cherry	42
Chestnut	41
Cork	15
Cypress	37
Ebony	76
Elm	35
Elm, Canadian	45
Greenheart	70
Hickory	53
Jarrah	63
Larch	34
Mahogany, Spanish	60
Mahogany, Honduras	35
Oak, English	60
Oak, American	53
Pine, White	25
Pine, Yellow	35
Pine, Red	40
Pine, Pitch	45
Plane	40
Poplar	25
Spruce	30
Sycamore	37
Teak	50
Walnut	40
Miscellaneous	
Anthracite, Broken, Loose	54
Asbestos	187
Asphalt	88
Coal, Bituminous	85
Coal, Broken, Loose	50
Coke	45
Coke, Loose	30
Flour	40
Glass, Window	160
Glass, Flint	190
Grain, Wheat	48
Grain, Barley	39
Grain, Oats	32
Hay and Straw in bales	20
Ice	59
Salt	45
Sulphur	125
White Lead	197

TABLE IV

APPROXIMATE WEIGHTS OF ROOFING MATERIALS, ETC.

In Lb. per Square Foot of Surface

Asphalt per 1 in. thick	7–13
Asphalted Felt	½
Boarding per 1 in.	3½
Corrugated Sheeting, 18G	2¼
Purlins	1¾
Glass, ¼ in. thick	3½
Glazing Bars	1½
Putty	⅜
Purlin	2
Lead (net)	7
Lead with Laps and Rolls	9
Plaster, Ceiling, per 1 in. thick	9
Slates, 3 in. lap, with nails	8½
Wood Purlins	2¾
Tiles, Plain, 10½ in. × 6 in. × ½ in. with Mortar for Pointing—	
8 in. gauge	16
7 in. gauge	18½
6 in. gauge	21
Angle Purlins	3¼

Vibration. Serious vibration may be set up in a structure due to repeated impulses, if the time period of the impulses happens to coincide with the natural period of vibration of the structure; it is to avoid such risk that marching troops are ordered to break step when crossing a bridge.

It may sometimes happen that a floor carrying vibrating machinery may have a natural period of vibration responding to that of the machine, in which case undue vibration results. In the present state of our knowledge this contingency cannot be foreseen, but it may be cured by altering the speed or position of the machine, or even by adding extra weight to the floor.

Wind Loads. Though knowledge of the effect of wind is considerably greater now than it was when the Tay Bridge was wrecked in 1879, there is still much that is not definitely known.

It is known that the wind load on a structure is influenced by its shape. Thus the side load on a square chimney is about twice that on a circular chimney having a diameter equal to the side of the square, the relative values for square, octagonal, hexagonal, and circular being approximately 1, $\frac{3}{4}$, $\frac{5}{8}$, and $\frac{1}{2}$ respectively.

It is also known that, other conditions being the same, the higher a structure is placed the greater may be the pressure upon it, and also that the smaller the exposed part the greater is the average pressure, this last effect being probably due to local gusts of higher velocity than the average.

The effect of adjacent structures on the intensity of wind pressure is difficult to estimate. As one more often hears of windows being blown out than blown in, it is reasonable to assume that the suction effect of wind may be greater than its direct pressure.

Experiments at the National Physical Laboratory, on roof models, show that the outward normal pressure on the leeward side may be greater than the inward normal pressure on the windward side, when the windward side is open and there is no through passage for the wind on the leeward side. In sports stands this effect may be relieved by openings in the leeward wall.

The latest experiments at the National Physical Laboratory indicate that the pressure on an exposed plane surface in lb. per sq. ft. equals the square of the velocity, in miles per hour, of the wind blowing normal to the surface, multiplied by ·0032.

If Smeaton's wind velocity table (in which he gave 50 miles per hour as a storm, 60 as a violent storm, 80 as a hurricane, and 100 as a violent hurricane) is a safe guide, a pressure of 30 lb. per sq. ft. should be adequate for exposed structures in this country.

Near the ground this pressure may be considerably reduced. The Belgian Standard specification for structural steelwork gives the basis wind pressure as about 20 lb. per sq. ft. For walls up to 50 ft. high the wind load is to be taken as 10 lb.; from 50 ft. to 66 ft. as 15 lb.; from 66 ft. to 82 ft. as 20 lb.; and above that 25 lb. per sq. ft. For buildings in open country, 25 lb. per sq. ft. is to be taken for all heights.

Except for buildings on the sea coast and similarly exposed situations, B.S.S. 449 specifies 15 lb. per sq. ft. of the upper two-thirds of the vertical projection of the surface of the building, as the wind pressure in any horizontal direction, with an additional pressure of 10 lb. per sq. ft. on all projections above the general roof level.

If, however, the building is not higher than twice its breadth, and is adequately stiffened by floors and walls, the wind pressure may be neglected.

Roof Loads. The wind pressure on a surface inclined to the direction of the wind is taken as normal to the surface. It is not, however, the normal component of the horizontal pressure; the normal pressure on a sloping surface 60°, with the horizontal being practically the same as on a vertical surface. The best known formulae for arriving at the normal pressure on a surface inclined at an angle i with the horizontal are (1) Hutton's, which gives the ratio of the normal pressure to that on a vertical surface (the direction of the wind being horizontal) as $\sin i^{(1{\cdot}84 \cos i - 1)}$; and (2) Duchemin's, which gives the ratio as $\frac{2 \sin i}{1 + \sin^2 i}$. Their values for various slopes are given in Table V.

If these values are plotted on radial lines on tracing cloth, as indicated in Fig. 3, on superimposing the tracing on a drawing of the sloping surface, so that O is above the intersection of the slope, with a horizontal line coinciding with the horizontal line on the tracing, the value for the ratio can be read at the intersection of the slope with the curve.

Snow loads (say 7 lb. to 13 lb. per sq. ft.) are rarely serious in this country, and can hardly occur on a sloping surface in conjunction with full wind load.

The possible load (other than snow load) on a flat roof depends on its accessibility; 30 lb.

TABLE V—RATIO OF NORMAL PRESSURE ON SLOPING SURFACE TO PRESSURE ON SURFACE NORMAL TO WIND

Inclination of Surface to Direction of Wind	5°	10°	15°	1/3	1/2½	1/2	30°	1/1½	40°	45°	50°	60°
By Hutton's Formula	·13	·24	·35	·42	·49	·59	·66	·73	·83	·90	·95	1·00
By Duchemin's Formula	·17	·34	·48	·57	·65	·74	·80	·85	·91	·94	·97	·99

per sq. ft. is often an ample allowance. As the slope increases the chance of a crowd of people coming on the roof decreases. The requirements for roofs specified in B.S.S. 449 are given in Table I.

The horizontal load will be the horizontal component of the normal wind load.

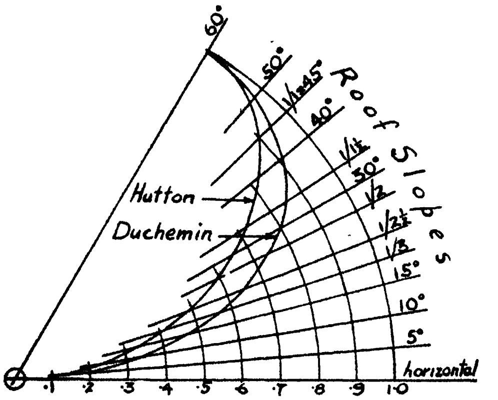


FIG. 3

Partitions. The position of partitions is often not settled till a building is complete, but an allowance for light partitions may usually be considered as included in the design load.

For all floors of rooms used for offices, B.S.S. 449 requires an allowance of not less than 20 lb. per sq. ft., when the position of partitions is not known.

The weight per square foot of a hollow tile partition may be taken as 16 lb. per sq. ft., with an extra of 6 lb. for every 2 in. thickness greater than 4 in., and a further extra of 5 lb. for each side plastered.

Loads on Main Beams and Columns. If the floor and secondary beams are designed for the full load, it is sometimes permissible to assume that the area of floor carried by the main beams is not fully loaded. A 25 per cent reduction of the live load may sometimes be reasonable, but the reduction, if any, depends on circumstances.

The probability that all floors will be fully loaded at the same time is, except for warehouses, very remote, and it is usual to reduce the live load coming on the columns.

A common allowance is 10 per cent to be deducted from the live load on the floor next below the top, 20 per cent from the next, and so on, but not more than 50 per cent. B.S.S. 449, however, does not permit these reductions for floors with a superimposed load of 100 lb. or more per sq. ft.

The live loads on roof and top story are usually taken in full, as the resulting columns will not usually be excessive for general stability.

It is permissible also to reduce the column loads due to wind, and often to ignore them altogether when stresses, due to wind, are not more than 33⅓ per cent of those due to dead and live load.

To reduce the dead load due to the weight of the floor itself, various methods, such as hollow tile floors, light-weight concrete, and the use of pre-stressed steel in high-grade, rich mix concrete, are adopted. It does not always follow that the dead loads should be kept to a minimum. For instance, in steel-framed buildings, housing heavy machinery, such as lathes, planers, gear cutters, grinders, rock crushers, etc., heavy floor girders, stout columns, and rigid connections, are more important than the saving of a few tons of steel, resulting in an unsatisfactory, unsteady job. In these special cases too much attention cannot be given to details. Good stiff gussets and bracings are essential if the floors are to remain steady enough to allow accurate machining being done.

By using welded roof trusses some saving in steel can be effected. In many industrial buildings the roof trusses are made with lower chords of steel channels to which runways are fixed, and in such instances it is wise to have sufficient height between the floor and the underside of the roof. A foot or two extra height, even if it adds to the amount of steel and the cost of the building, can be true economy. Where the building is a shed or cover without floors, or where the floors need not be free from vibration, then by accurately working out loads and stresses a good designer can often save tons of steel.

Chapter III—DEFINITIONS

IDEAS are conveyed by terms which are often used loosely with varying shades of meaning, and it is difficult to give exact scientific definitions and consistently to keep to them, nor is it easy to know what terms are sufficiently technical to need definition.

Stress. When force is transmitted through a material, the latter is said to be *stressed.* Provided the material is homogeneous, that is, of uniform consistency, the stress is independent of the material used.

Thus, if a load of 100 lb. is lifted by a round bar 1 sq. in. in sectional area, the stress in the bar will be 100 lb. per sq. in., whether the bar is steel, glass, or copper.

It would have been more scientific to have said "The *intensity of stress* in the bar, etc.," instead of "the *stress* in the bar, etc."; but common usage permits the omission of "intensity of," and stress will hereafter be used to express a force or load per unit area, equalling total force divided by total stressed area if the stress is uniformly distributed.

If the 100 lb. weight had been lifted by a hook at the end of the bar, the stress would have varied across the section in a way that will be discussed later, in which case 100 lb. per sq. in. would be the average stress.

A force acting on a section at any point may be ***normal*** to the section (i.e. at right angles to it), ***tangential*** (i.e. parallel to the section), or inclined at an angle; in the latter case the force will have both normal and tangential components. Thus, if the direction of a force F is inclined at an angle θ with the normal to a surface, as indicated in Fig. 4, its effect is equivalent to a force $F \cos \theta$ acting normally to the surface, together with a force $F \sin \theta$ acting parallel to the surface, the components of F being the sides of the triangle of force (in this case right angled) of which the longest side, or hypotenuse, is drawn to scale to represent the force F in magnitude and direction. If the area of the plane surface on which the force is acting is A, then the average normal stress is $F \cos \theta/A$ and the average tangential stress is $F \sin \theta/A$.

A normal force may be a pull, in which case the stress set up is one of ***tension***; or a push (as indicated in Fig. 4), in which case the stress is one of ***compression***. A tangential force sets up a ***shear*** stress.

PRINCIPAL STRESSES. At any vertical section of a loaded beam there is a normal stress due to the bending action of the beam, and shear stress acting along the vertical section, due to the shearing forces acting on the beam.

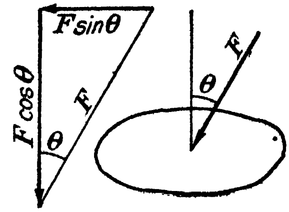


FIG. 4

In actual practice it is usual to consider the bending and shear stresses separately, but the fact must not be lost sight of that with a normal stress, i.e. compression or tension, acting in conjunction with a shear stress, there may be points in a beam at which the intensity of stress due to the combined effect of the normal and shear stress is greater than the greatest stress due to either bending or shearing taken separately.

The stress due to bending will be greatest at the outermost fibres, diminishing to zero at the neutral axis. The stress due to shear is greatest at the neutral axis, but diminishes towards the flanges.

At the inner side of the flange there is a stress due to bending of intensity almost equal to the maximum bending stress, and there is also a shear stress of considerable magnitude, little less in fact than the maximum shear stress. Therefore, the greatest intensity of stress due to the combined action of bending and shear will occur at the junction of the web with the flanges, and in certain cases, such as heavily loaded short beams, it is necessary to calculate the combined stress in order to see if this is within safe limits. It can be found that—

$$f_e = \frac{f_t}{2} \pm \sqrt{f_s^2 + \frac{f_t^2}{4}}$$

Where f_e is the stress resulting from combination of a tensile and shear stress.

f_t is the tensile stress due to bending.

f_s is the shear stress.

This formula will evidently apply to the portion of the beam which is in tension, i.e. the lower portion.

It will be noticed that two results can be obtained from the formula, and the following explanation will make the reason for this clear.

Fig. 5A shows a beam supported at each end. Fig. 5B shows an enlarged view of the small piece *a* at the bottom of the web. This piece will be subject to tensile and shear stresses as shown.

The shear forces can be resolved into four separate forces each acting at a corner of the piece, as shown in Fig. 5C, namely, *A*, *B*, *C*,

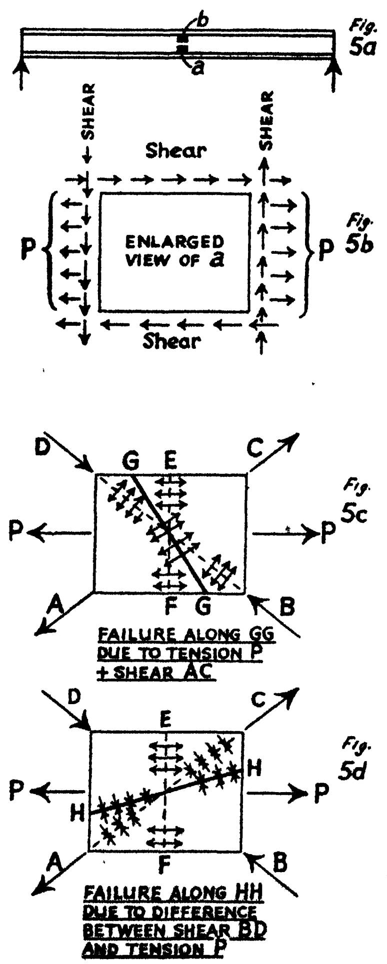


FIG. 5

and *D*. Two of the shear forces act towards the centre of the block and the other two away from the centre.

Then force *AC* would by itself cause failure along a line *BD*, by tearing the block apart. Forces *P* (tensile stress due to bending) tend to pull the block apart along a plane *EF*. The addition of the shear stresses (causing forces *A* and *C*) and the tensile bending stresses (causing *P*) will cause failure along a plane approximating to *GG* in Fig. 5C. It will be noticed in this case that both the bending stress and shear stress are in tension, and therefore the total force will be an addition, and the formula will be

$$f_e = \frac{f_t}{2} + \sqrt{f_s^2 + \frac{f_t^2}{4}}$$

f_e obtained with this formula will *always* be tension.

Now consider Fig. 5D. The shear forces *BD* tend to cause buckling of the block along a line *AC*, but clearly the tensile pull *P* due to the bending stress tries to pull the block apart along *EF*.

Therefore the plane of lesser principal stress (i.e. when a minus sign occurs in the formula) will occur on a line approximating to *HH*. In this case the stress will clearly be less than it was before, as we have one force pulling and one force pushing, so that the net result is the difference between these two forces.

The formula for this case is—

$$f_e = \frac{f_t}{2} - \sqrt{f_s^2 + \frac{f_t^2}{4}}$$

f_e will *always* be a compressive stress in this formula.

If the piece of web which is in compression, i.e. piece *b*, is taken, the same reasoning can be applied, except that the forces *P* are now causing compression on the block.

Then if

f_c is the compressive stress due to bending;

f_e is the stress due to a combination of compressive bending stresses and shear stresses;

f_s^1 is the shear stress;

$$f_e = \frac{f_c}{2} + \sqrt{f_s^2 + \frac{f_c^2}{4}}$$

when the shear is assumed as a compressive stress (f_e is always Compressive)

and
$$f_e = \frac{f_c}{2} - \sqrt{f_s^2 + \frac{f_c^2}{4}}$$

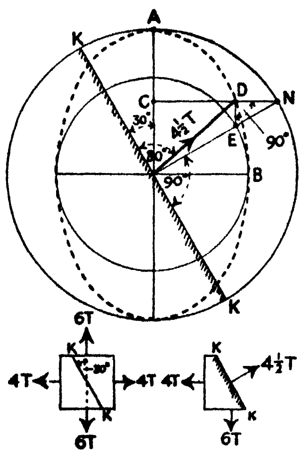
when the shear is assumed as a tensile stress (f_e is always Tensile)

therefore
$$f_e = \frac{f_c}{2} \pm \sqrt{f_s^2 + \frac{f_c^2}{4}}$$

The greater principal stress, as given by this formula when the positive sign is used, will be *compressive*, and the lesser principal stress, as given when the negative sign is used, will be *tensile.*

EXAMPLE. Show how to use a circular diagram to represent the intensity of stress and its direction on any plane at a point in a material subject to two given principal stresses, the third one being zero. Draw the diagram for the case when one principal stress is 6 tons per square inch tensile and the other is 4 tons per square inch tensile, and indicate on your diagram the stress in magnitude and direction on a plane inclined 30 degrees to that of the greater principal stress.

SOLUTION. Draw two concentric circles, the radius of the larger representing to scale the larger principal stress, and the radius of the smaller circle the smaller principal stress. Then an ellipse drawn with the larger circle as its width and the smaller circle as its height will give the value of the stress on any plane inclined to the principal stresses.



Strain. The change of dimensions in a material due to a stress is termed a *strain.* The same stress will produce different strains in different materials. A tensile stress will produce lengthening in the line of action of the stress; a compressive stress will produce a shortening; and a shear stress a distortion (see Fig. 6).

In a *plastic* material, such as lead, for all but very low stresses the strains are permanent; but in an *elastic* material the deformations are temporary, and the material returns to its original shape when the load is removed.

Elastic Modulus. If a steel bar of length l is submitted to a tensile stress t, its length will be increased. If this increase in length is plotted as a horizontal ordinate with the corresponding stress as a vertical ordinate, the resulting graph is a straight line.

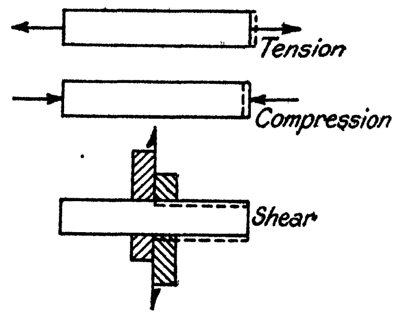


FIG. 6

$$\text{Stress} = \frac{\text{Load}}{\text{Area}}$$

$$\text{Area} = \frac{\text{Load}}{\text{Stress}}$$

$$\text{Load} = \text{Stress} \times \text{Area}$$

$$\text{Stress} = \text{Modulus of elasticity} \times \text{Strain}$$

$$\text{Stress} = \frac{\text{Bending moment}}{\text{Section modulus}}$$

$$\text{Strain} = \frac{\text{Stress}}{\text{Modulus of elasticity}}$$

$$\text{Strain} = \frac{\text{Bending moment}}{\text{Modulus of elasticity} \times \text{Section modulus}}$$

$$\text{Strain} = \frac{\text{Change of length}}{\text{Original length}}$$

$$\text{Change of length} = \text{Strain} \times \text{Original length}$$

$$\text{Original length} = \frac{\text{Change of length}}{\text{Strain}}$$

$$\text{Modulus of elasticity} = \frac{\text{Stress}}{\text{Strain}}$$

$$\text{Modulus of elasticity} = \frac{\text{Stress} \times \text{Original length}}{\text{Change of length}}$$

$$\text{Modulus of elasticity} \doteq \frac{\text{Bending moment} \times \text{Original length}}{\text{Section modulus} \times \text{Change of length}}$$

$$\begin{array}{c}\text{Modulus of rigidity}\\ \text{or shear modulus}\end{array} = G = \frac{\text{Shear stress}}{\text{Shear strain}}$$

The torsional resistance of a bar is proportional to the modulus of rigidity.

A sensitive extensometer shows a slight divergence from the straight line, the curve as the load increases lying above the curve for a decreasing load, forming what is known as a *hysteresis loop*. For all practical purposes, however, Hooke's law, *ut tensio sic vis*, usually

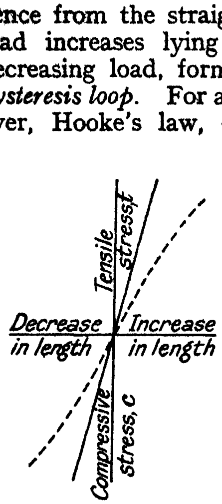


FIG. 7

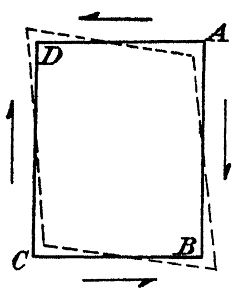


FIG. 7A

rendered "strain is proportional to stress," holds good for steel for the stresses used in design.

If the stress, instead of being tensile, is compressive, the length of the bar is decreased; and if this decrease is plotted against the compressive stress c, the resulting graph will be found to be in the same straight line as that for tensile stresses, as indicated by the full line in Fig. 7.

The actual length difference (δl) will also be proportional to the original length (l), and therefore may be written

$$\delta l = l \cdot c/E \text{ or } \delta l = l \cdot t/E \qquad . \quad . \quad (4)$$

where the value of E can be found from experiment.

This constant E is known as *Young's modulus of elasticity*. Its value for steel is about 30,000,000 lb. per sq. in., or about 13,000 tons per sq. in.

From the last equation, we get

$$E = t \text{ (or } c) \div \delta l/l \quad . \quad . \quad . \quad (5)$$

where $\delta l/l$ represents the alteration in length of every unit of length and may be termed the *unital strain*. Hence E = stress $\div$ unital strain.

If similar graphs are drawn for cast iron, wood, or concrete, it is found that instead of being approximately straight, as for steel and wrought iron, they are curved as indicated by the dotted line in Fig. 7. The value of E (which is proportional to the tangent to the inclination of the curve) is thus a maximum for the lowest stresses, and decreases as the stress increases.

For example, the test of a particular bar of cast iron showed $E = 6{,}073$ tons per sq. in. for a stress of 1 ton per sq. in., 5,528 for 3 tons per sq. in., and 4,400 for 6 tons per sq. in.

In using E in calculations, it should be recognized that the value assigned may be true for only one particular stress, and that for calculating the total extension of a bar at the stress on the assumption of a constant value for E, the value to use must be intermediate between the value at that stress and the initial value.

It will therefore be clear that the results of such calculations must not be interpreted too rigidly.

Poisson's Ratio. If a bar is stretched or compressed elastically, its dimensions at right angles to the direction of the stress are decreased or increased. The ratio of the lateral unital strain to the longitudinal is known as *Poisson's ratio*, and may be written $1/n$ where the value of n for steel is about 4.

Thus, if a 1 in. diameter steel bar is loaded to produce a stress of 30,000 lb. per sq. in., the increase (or decrease) in length for every inch will be, from equation (5), $t \div E = 30{,}000 \div 30{,}000{,}000 = \cdot 001$; and the decrease (or increase) in the diameter of the bar will be $\frac{1}{n} \times \cdot 001 = \cdot 00025$, if $n = 4$.

Similarly, a compressive axial stress in a concrete column produces an increase in the diameter of the column. If the column is cast with horizontal binding to prevent the natural increase in the diameter, the column is capable of carrying a greater axial load.

Rigidity Modulus. If $ABCD$ in Fig. 7A is a section of a small rectangular prism of material of unit thickness and is subjected to a sheer stress s on the two faces AB and CD, the load on AB will be $s \cdot AB$ and on CD, $s \cdot CD$. These forces tend to produce clockwise rotation of the prism, the value of the rotating moment being $s \cdot AB \cdot BC = s \cdot CD \cdot DA$.

If the prism is in equilibrium, there must be reactions along AD and CB from the adjacent material tending to produce the same rotating moment in the opposite direction. As AB is the lever arm for this moment, the reactions must be $s \cdot AD = s \cdot CB$, that is, the stress along AD and CB must be s, the shear stress acting along AB and CD.

It will be noted that $s \cdot AD$ and $s \cdot AB$ combine to give a compressive force $s \cdot AC$ acting along AC, and balanced by the compressive stress $s \cdot CA$, resulting from the combination of $s \cdot CB$ and $s \cdot CD$.

Similarly, $s \cdot AD$ and $s \cdot CD$ combine to give a tensile force $s \cdot BD$ acting along the other diagonal BD, and balanced by the tensile force due to $s \cdot CB$ and $s \cdot AB$. The diagonal AC will thus be shortened and the diagonal BD lengthened, as the rectangle will be distorted as indicated in Fig. 7A.

This distortion is measured by the tangent of the angular difference (ϕ) between the angles at the corners of the distorted figure and the original right angles. As the angle is very small, tan ϕ equals the value of ϕ measured in radians, that is, the length of the arc of a circle of unit radius subtended by the angle ϕ at the centre.

This angle ϕ, termed the shear strain, equals the shear stress s divided by the *rigidity modulus* G, that is, $\phi = s/G$ . . . . . (6)

For steel the value of G is about $\cdot 4 \times E$. If, in the figure $AB = BC$, the diagonals will cut one another at right angles, and there will be no shear stress along them.

The compression $s \cdot AC$ acts on an area BD, which equals AC, so that the diagonal compressive stress equals s. Similarly, the tensile stress along the other diagonal direction equals s. It is thus seen that a pure shear is equivalent to pure compression and tension in directions at 45° with the direction of the shear stress, and these are principal stresses.

Relation Between Elastic Constants. In the elementary analyses necessary for building construction design, it will rarely be necessary to refer to any elastic constant other than E. A clearer understanding, however, of what is required in design will be gained if an attempt is made to visualize what happens when a structural material undergoes strain.

It is thus of interest to examine the relationship between the foregoing constants, though many excellent buildings have been designed and erected by engineers who have rarely given a thought to any of them.

If a pure shear stress s acts on four faces of the cube of which $ABCD$ in Fig. 8 is a cross-section, the result has been shown equivalent to a compressive stress s in the direction AC and a tensile stress s in the direction BD. The original length of the diagonals AC and BD is $\sqrt{2} \cdot l$, where $l = AB = BC$; the tensile stress increases the length to $\sqrt{2} \cdot l \cdot (1 + s/E)$; and the compressive stress decreases the length to $\sqrt{2} \cdot l \cdot (1 - s/E)$.

The compressive stress along AC increases further the length of BD from $\sqrt{2} \cdot l \cdot \left(1 + \frac{s}{E}\right)$ to $\sqrt{2} \cdot l \cdot \left(1 + \frac{s}{E}\right)\left(1 + \frac{s}{E \cdot n}\right)$, and the tensile stress decreases the shorter diagonal to $\sqrt{2} \cdot l \cdot \left(1 - \frac{s}{E}\right)\left(1 - \frac{s}{E \cdot n}\right)$.

The change of length of each diagonal is thus the same, viz., $\sqrt{2} \cdot l \cdot \frac{s}{E} \cdot \left(1 + \frac{1}{n}\right)$, the last term resulting from the multiplication of the

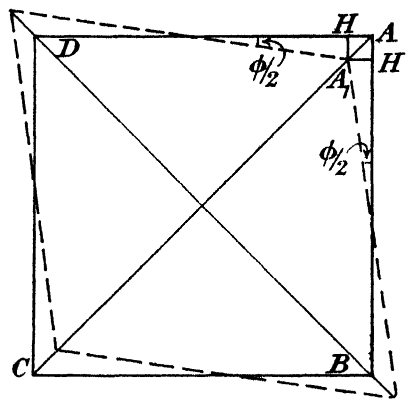


FIG. 8

expressions in the brackets being $s^2 \div E^2 \cdot n$, and therefore negligible.

From Fig. 8 half of this change equals AA_1, which is the hypotenuse of a triangle of which A_1H is the base and $AA_1 = \sqrt{2} \cdot A_1H$ But $A_1H = \frac{l}{2} \cdot \frac{\phi}{2}$, as ϕ is very small,

$$\therefore \frac{\sqrt{2} \cdot l}{2} \cdot \frac{s}{E} \cdot \left(1 + \frac{1}{n}\right) = \sqrt{2} \cdot \frac{l}{2} \cdot \frac{\phi}{2}$$

$$= \frac{\sqrt{2} \cdot l}{2} \cdot \frac{1}{2} \cdot \frac{s}{G} \text{ as } \phi = \frac{s}{G} \text{ (from equation 6).}$$

$$\therefore \left(1 + \frac{1}{n}\right) \div E = \frac{1}{2G} \quad . \quad . \quad (7)$$

If $n = 4$, $G = \cdot 4E$.

Properties of Sections. Before it is possible to investigate the stresses in a structural member

it is necessary to know the properties depending on its shape.

If two axes OX and OY are drawn outside the section, which is divided up into narrow

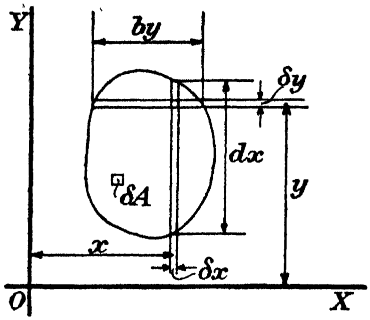


FIG. 9

strips parallel to the axes, the total area is the sum of such strips, and may be written

$$A = \Sigma by \,.\, \delta y = \Sigma dx \cdot \delta x$$

where by and dx are the breadth and depth respectively of the strips a distance y and x from he axes, as shown in Fig. 9.

If a small element of area is called δA the total area may also be written as $\Sigma\delta A$. The symbol Σ (sigma) is the Greek letter S, and is commonly used to signify summation.

If the area of each horizontal strip is multiplied by its distance from OX, the sum may be written $\Sigma by \cdot \delta y \cdot y$, and is called the *first moment* of the area about the axis OX. If this area moment is divided by the area, the quotient is a length which may be called y_0.

Thus,

$$y_0 \times \Sigma by \cdot \delta y = \Sigma by \cdot \delta y \cdot y \quad . \quad . \quad (8)$$

Similarly,

$$x_0 \times \Sigma dx \cdot \delta x = \Sigma \delta x \cdot \delta x \cdot x \quad . \quad . \quad (9)$$

The two co-ordinates x_0 and y_0 determine the *centroid* of the area, or the point where the whole area may be considered to act, in determining the first moment of the area about any axis. The second moment of the area, or the *moment of inertia*, (I) about OX, may be written $Ix = \Sigma by \cdot \delta y \cdot y^2$.

If this is divided by the area, the quotient is an area which may be written g_x^2.

Thus,

$$Ix = \Sigma by \cdot \delta y \cdot y^2$$
$$= (\Sigma by \cdot \delta y) \cdot g_x^2 = A \cdot g_x^2 \quad . \quad (10)$$

Similarly,

$$Iy = \Sigma dx \cdot \delta x \cdot x^2$$
$$= (\Sigma dx \cdot \delta x) \cdot g_y^2 = A \cdot g_y^2 \quad . \quad (11)$$

The distances g_x and g_y are termed the *radii of gyration* of the section about the axes OX and OY respectively.

If axes O_1X_1 and O_1Y_1 are drawn through the centroid parallel to OX and OY, as shown in

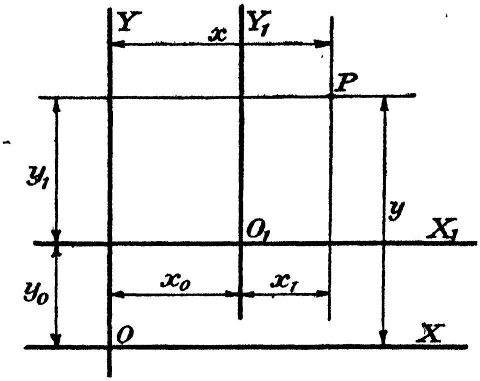


FIG. 10

Fig. 10, the co-ordinates of any point P are x_1 and y_1 with reference to the new axes, and x and y with reference to the old. Then, $y = y_0 + y_1$, and $x = x_0 + x_1$; also $\Sigma by \cdot y \cdot \delta y = y_0 \, \Sigma by \cdot \delta y + \Sigma by \cdot y_1 \cdot \delta y$.

From (8) $\Sigma by \cdot y \cdot \delta y = y_0 \, \Sigma by \cdot \delta y$.

$$\therefore \; \Sigma by \cdot y_1 \cdot \delta y = 0 \quad . \quad . \quad . \quad (12)$$

Similarly,

$$\Sigma dx \cdot x_1 \cdot \delta x = 0 \quad . \quad . \quad . \quad (13)$$

$$\Sigma by \cdot \delta y \cdot y^2 = y_0^2 \, \Sigma by \cdot \delta y + \Sigma by \cdot \delta y \cdot y_1^2 + 2y_0 \, \Sigma by \cdot \delta y \cdot y_1.$$

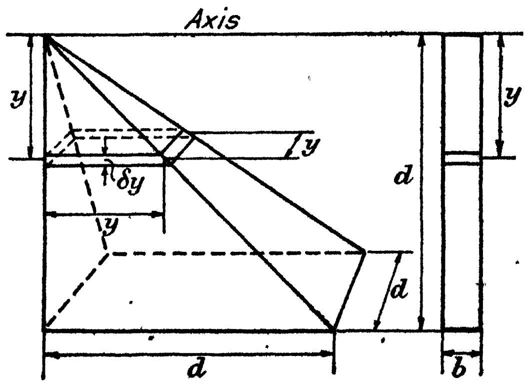


FIG. 11

From (12) the last term $= 0$; therefore

$$\Sigma by \cdot \delta y \cdot y^2 = y_0 \, \Sigma by \cdot \delta y + \Sigma by \cdot \delta y \cdot y_1^2,$$

which may be written

$$Ix = A \cdot y_0^2 + Ix_1 \quad . \quad . \quad . \quad (14)$$

Similarly,

$$Iy = A \cdot x_0^2 + Iy_1 \quad . \quad . \quad . \quad (15)$$

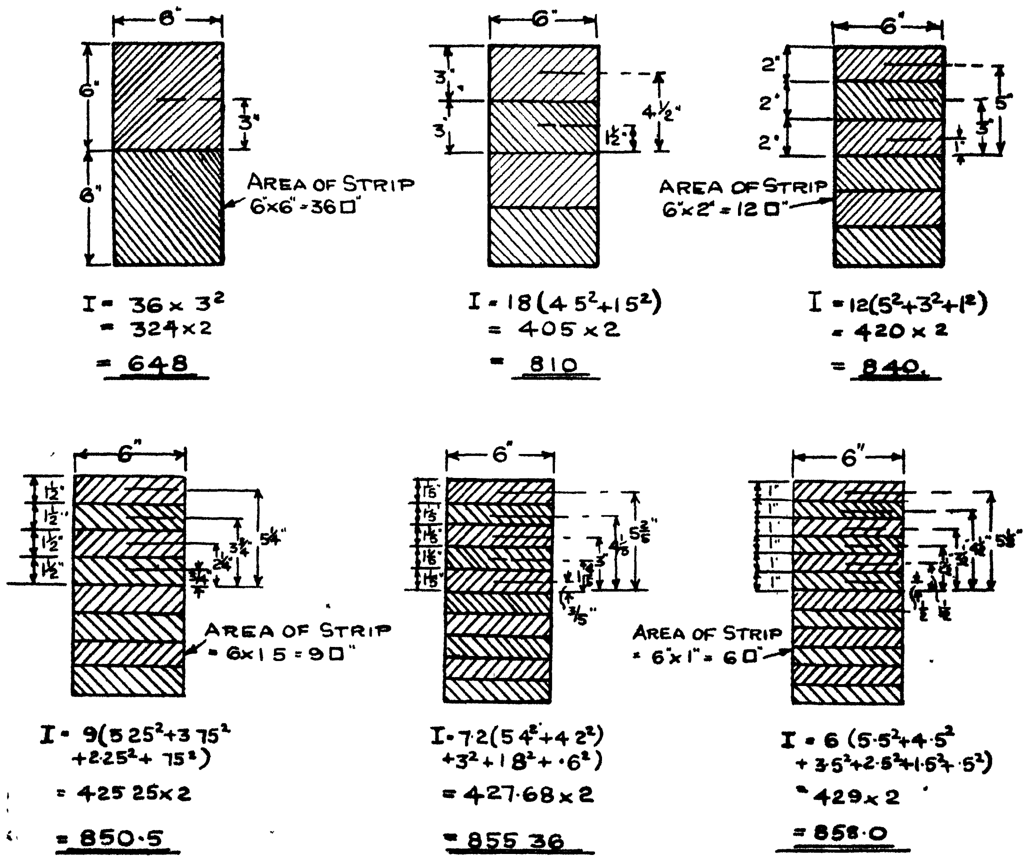
These last equations enable the moment of inertia about an axis through the centroid to be readily obtained when the area of the section, the position of the centroid, and the moment of inertia about any parallel axis are known.

The moment of inertia of a rectangle of area $b \cdot d$ about the axis shown in Fig. 11, is $\Sigma b \cdot \delta y \cdot y^2 = b\Sigma\delta y \cdot y^2$. If a pyramid is drawn with a square base of area d^2 and height d, $\delta y \cdot y^2$ is clearly the volume of a thin horizontal

MOMENTS OF INERTIA

Moment of Inertia of Rectangle, 12″ × 6″

Inertia of each Area $= a \times d^2$
Total Inertia $= \Sigma a \times d^2 = A \times d^2$



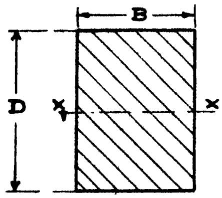
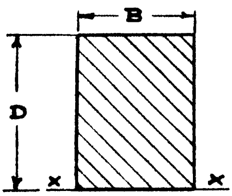
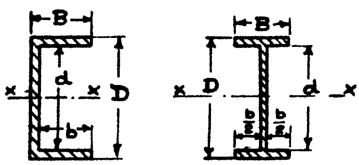
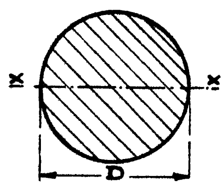
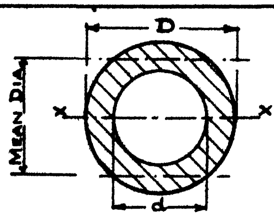
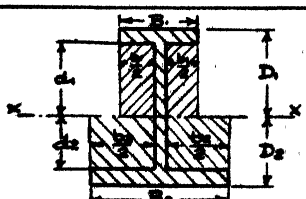
$$\text{Moment of Inertia} = A \times d^2 = \frac{BD^3}{12} = \frac{6 \times 12 \times 12 \times 12}{12} = 864$$

$$\text{Radius of Gyration} = \sqrt{\frac{I}{A}} = \sqrt{\frac{\frac{BD^3}{12}}{B \times D}} = \sqrt{\frac{D^2}{12}} = \frac{D}{3{\cdot}46} = {\cdot}289D$$

$$\text{Modulus} = \frac{I}{y} = \frac{\frac{BD^3}{12}}{\frac{D}{2}} = \frac{BD^2}{6}$$

FIG. 12

TABLE VI.

MOMENT OF INERTIA...... SECTION MODULUS..... RADIUS OF GYRATION			
SECTION	MOMENT OF INERTIA (ABOUT AXIS X.X.)	SECTION MODULUS (AXIS X.X.)	RADIUS OF GYRATION (AXIS X.X.)
	$I_{xx} = \frac{BD^3}{12}$	$\frac{BD^2}{6}$	·29 D
	$I_{xx} = \frac{BD^3}{3}$	—	$\frac{D}{\sqrt{3}} = \frac{D}{1{\cdot}73}$
	$I_{xx} = \frac{BD^3 - bd^3}{12}$	$\frac{BD^3 - bd^3}{6D}$	·4 D (APPROXIMATE ONLY)
	$I_{xx} = \frac{\pi D^4}{64}$	$\frac{\pi D^3}{32}$	·25 D
	$I_{xx} = \frac{\pi}{64}(D^4 - d^4)$	$\frac{\pi}{32}\frac{(D^4 - d^4)}{D}$	$\sqrt{\frac{D^2 + d^2}{4}}$ APPROXIMATELY ·35 MEAN DIA
	$I_{xx} = \frac{1}{3}(B_1D_1^3 - b_1d_1^3) + \frac{1}{3}(B_2D_2^3 - b_2d_2^3)$	$Z_1 = \frac{I}{D_1}$ $Z_2 = \frac{I}{D_2}$	$\sqrt{\frac{I}{A}}$

strip, and $\Sigma dy \cdot y^2 =$ total volume $= d^3/3$.

I about end $= bd^3/3 = Ad^2/3 = A\left(\frac{d}{2}\right)^2 +$ I about centre, from (15).

$$I \text{ about centre} = A \cdot d^2/3 - A \cdot d^2/4$$
$$= A \cdot d^2/12 = b \cdot d^3/12 \quad . \quad (16)$$

By those familiar with the integral calculus this may be obtained directly, for

$$I = \int_{-d/2}^{d/2} b \cdot y^2 \cdot dy = b \cdot d^3/12$$

Fig. 12 shows a rectangle split up into a number of pieces. Notice that when the number of pieces gets bigger and bigger we get closer and closer to the correct m of I calculated by the formula.

For the circle and triangle the corresponding values of Ix are

$$A \cdot d^2/16 \text{ and } A \cdot d^2/18 \text{ respectively} \quad . \quad (17)$$

The moment of inertia about an axis through the centroid perpendicular to the section is

$$\Sigma\delta A \cdot (x^2 + y^2) = Iy + Ix \quad . \quad . \quad (18)$$

Table VI gives the values of moment of inertia, section modulus, and radius of gyration.

EXAMPLE. A rolled steel joist 12 in. deep by 6 in. wide, weighing 54 lb per foot, will have dimensions approximately as follows—

Thickness of flanges = 1 in.

Thickness of web = $\frac{1}{2}$ in.

Using the value given in Table VI the moment of Inertia about line xx will be

$$\text{M. of I} = \frac{BD^3 - bd^3}{12} \text{ in.}^4$$

from the dimensions given above

$B = 6$ in., $b = 5\frac{1}{2}$ in., $D = 12$ in., $d = 10$ in.

$$\text{M. of I} = \frac{6 \times 12^3 - 5\frac{1}{2} \times 10^3}{12}$$
$$= \frac{4868}{12}$$
$$= 405 \text{ in.}^4 \text{ units.}$$

This would be the greatest moment of Inertia. The least moment of Inertia would be used in the design of columns.

EXAMPLE. Two 15 in. × 6 in. rolled steel joists (R.S.J.) at 8 in. centres ($A = 17{\cdot}3$ inch², $Ix = 726$ inch⁴, $Iy = 27{\cdot}1$ inch⁴) are connected by a steel plate 18 in. × 1 in., riveted to top flange.

Find Ix and Iy of gross section, neglecting rivet holes.

SOLUTION. If A is area of constituent, y its distance from a chosen axis, Ic its moment of inertia about axis through its centroid, the calculation may be tabulated as below, the axes chosen being the bottom of the unplated flanges and the axis of symmetry parallel to the webs—

Member	*A*	*y*	*A·y*	*A·y²*		*Ic*		
2/15 in. × 6 in. R.S.J.	34·6	7½	259·5	1946·0	+	1452·0	=	3398
18 in. × 1 in. plate	18·0	15½	279·0	4324·5	+	1·5	=	4326
Total A =	52·6	× 10·25 =	538·5	Ix about bottom			=	7724
	52·6	× 10·25² =	538·5 ×	10·25			=	5520
Centroid is 10·25 from bottom and Ix about centroid							=	2204

Member	*A*	*y*	*A·y*	*A·y²*		*Ic*		
15 in. × 6 in.	17·3	+ 4	+ 69·2	276·8	+	27·1	=	303·9
15 in. × 6 in.	17·3	− 4	− 69·2	276·8	+	27·1	=	303·9
18 in. × 1 in. plate	18·0	0	0	0	+	486·0	=	486·0
	52·6			Iy about centroid			=	1094

The radii of gyration are: $g_x = 6{\cdot}48$ and $g_y = 4{\cdot}56$.

Chapter IV—BEAM THEORY

INTERNAL STRESSES

Section Modulus. Consider a cross-section of a structural member of any shape, such as that shown to the left of Fig. 13, called upon to resist forces due to loads acting in a direction parallel to the section, like those on the cantilever beam shown in Figs. 1 and 2. Let the sum of the

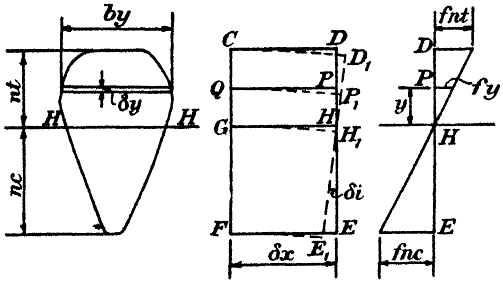


Fig. 13

loads to the right of the section be S, the ***shearing force*** acting on the section, and let the total leverage of the forces about the section (that is, the sum of the products of the forces and their distances from the section) be Bx, the ***bending moment*** at the section. Let $CDEF$ be a small longitudinal section of the unstrained beam ($CD = FE = \delta x$), where DE is the trace of the cross-section.

If the forces to the right of the section DE tend to produce clockwise rotation, the top portion will be in tension, and will be lengthened from CD to CD_1, and the bottom portion will be in compression, and will be shortened from FE to FE_1. There will obviously be one portion GH, along which there will be no tension or compression, and therefore $GH = GH_1$. This is termed the ***neutral axis*** of the beam, HH being the neutral axis of the section.

It is usual to assume that the section DE, which is plane before bending, remains plane (D_1E_1) after bending. Thus the change in the length of QP to QP_1 will be proportional to its distance (y) from the neutral axis.

If Hooke's law holds good, an assumption (often erroneous) usually made, the stresses on the section may be represented by the horizontal lines in the triangles shown on the right of Fig. 13.

If fy is the stress on any strip of height δy and breadth by a distance y from the neutral axis, then, by similar triangles,

$$fy/y = fnt/nt \quad . \quad . \quad . \quad . \quad . \quad (19)$$

The total load on the strip $= fy \cdot by \cdot \delta y = y \cdot fnt \cdot by \cdot \delta y/nt$.

The total tension on the top portion

$$= \frac{fnt}{nt} \cdot \Sigma_0^{nt} y \cdot by \cdot \delta y$$

$$= \frac{fnt}{nt} \text{ (area moment of top portion of cross-section about axis } HH) \quad (20)$$

Similarly, the total compression in the bottom portion

$$= \frac{fnc}{nc} \text{ (area moment of bottom portion of cross-section about axis } HH) \quad (21)$$

As there are no normal forces acting to the right of the section, the total tension must equal the total compression; therefore, as by similar triangles $fnt/nt = fnc/nc$, the values in the brackets of equations (20) and (21) must be equal; that is, ***the neutral axis must be on the centroid of the section.***

The moment about this axis of the forces acting on the section must equal B; therefore

$$Bx = \Sigma_0^{nt} fy \cdot by \cdot \delta y \cdot y + \Sigma_0^{nc} fy \cdot by \cdot \delta y . y$$

$$= \frac{fnt}{nt} \Sigma_0^{nt} by \cdot y^2 \cdot \delta y + \frac{fnc}{nc} \Sigma_0^{nc} by \cdot y^2 \cdot \delta y$$

$$= \frac{fnt}{nt} \cdot I_{HH} = \frac{fnc}{nc} \cdot I_{HH} \quad (22)$$

$\Sigma_0 \; by \cdot y^2 \cdot \delta y$ is the moment of inertia of the tension area about the axis HH. The centre of action of the tension, in equation (20), is thus

the moment of inertia of the tension area about the neutral axis, divided by the area moment of the tension area about the same axis. Similarly, for the compression area. The distance between the centres of action of the tension in the top portion, and the compression in the bottom portion, is termed the ***lever arm*** of the section.

In equation (22) the quantity $\frac{I_{HH}}{nt}$ is termed the ***section modulus*** for tension, and $\frac{I_{HH}}{nc}$ the section modulus for compression. It will be noted that for sections whose neutral axis is not central, there are two values of the section modulus. For a symmetrical section of depth d, the section modulus $M = I \div \frac{1}{2}d$; and the bending moment, at any section (B), is the product of the section modulus and the stress (f) at the edge of the section, that is

$$B = f \cdot M \qquad . \quad . \quad . \quad (23)$$

If f is the maximum allowable stress, the bending moment (B) equals the ***resistance moment*** (R).

Bending Moments. Bending moment has been described as the algebraic sum of all the external forces acting on either side of the point considered.

A moment is simply a force, or load, multiplied by an arm or a leverage. The farther from the point of balance a child gets when it is on a see-saw, the greater the moment. Take the simple case of a beam 10 ft. span and loaded with 1 cwt. in the middle. Each support will carry half the load. Now imagine that this is a see-saw; the beam is turned round and each support, instead of acting upward, acts downwards; and the load in the centre, instead of being a load, becomes a pivot for the see-saw. Then each side has a moment of force × leverage.

$$\begin{aligned} \text{Moment} &= \tfrac{1}{2}\text{ cwt.} \times \text{leverage.} \\ &= \tfrac{1}{2}\text{ cwt.} \times \tfrac{1}{2}\text{ length of beam.} \\ &= \tfrac{1}{2}\text{ total load} \times \tfrac{1}{2}\text{ span.} \end{aligned}$$

The bending moment we have now found applies to all beams which carry a load in the centre and are supported at the ends.

$$\text{Max. bending moment} = \frac{\text{Load} \times \text{Span}}{4}$$

UNITS. If the load is taken in tons and the span in feet, the bending moment will be in tons and feet (often written foot-tons). If the load is in tons and the span in inches, the bending moment will naturally be in tons and inches, or inch-tons. Foot-tons are used for the bending moment and inch-tons for the modulus of resistance.

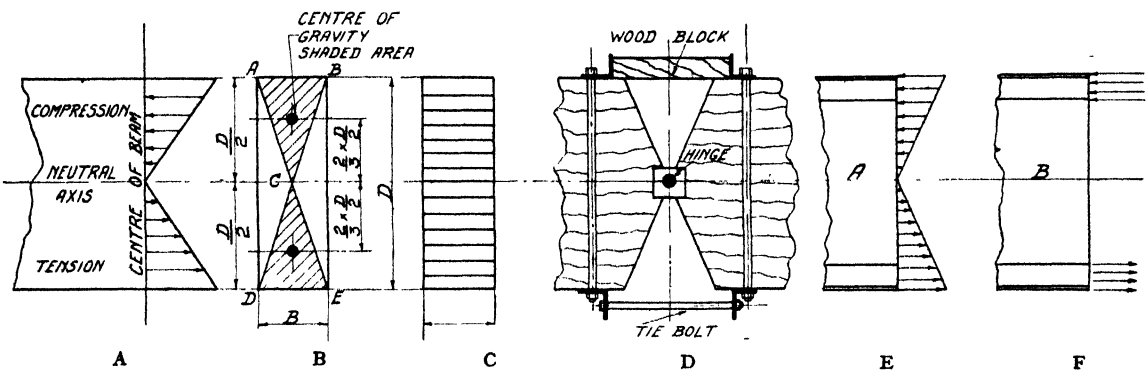


FIG. 14

Fig. 14. Imagine the centre portion of a beam supported at both ends to be cut away as shown in D, and a hinge fitted to prevent failure by shear. The beam might be made to support a load by bolting angles to the top and bottom of the beam, by packing a block between the top angles, and by fastening a tiebolt through the lower angles. If the block is placed on the bottom side, it would fall out when the beam came under load, because the angles tend to become wider apart; but it would be found on trial that the block on the top side would be squeezed, or in compression. This shows that the top side of the beam is under pressure (or in compression), and the lower part of the beam in tension (or tending to pull apart). Half-way between the top and bottom the beam would

not be under either compression or tension, and this is called the neutral axis. The farther from the neutral axis we place the block or the tie rod, the greater will be its arm or leverage to resist stresses. *A* shows the distribution of the stresses which are at a maximum at the outer fibres of the beam, and diminish to zero at the neutral axis.

In *A* we see the cross-section of a beam 14 in. by 3 in. divided into a number of equal slabs or rectangles. (A moment, which is a force times a distance, must be resisted by a force times a distance, that is, a force times a leverage.) If the material of which the beam is made is capable of safely resisting 1,000 lb. per sq. in., then the outer slab (which is 3 in. × 1 in. thick) will be capable of resisting 3,000 lb. We have already seen that the bending moment may be in tons and inches, tons and feet, or pounds and inches. Now if the top slab act at an arm or leverage of 6½ in., the resistance of that one slab will be 3,000 lb. × 6½ in. = say, 19,500 in. and lb. (or 19,500 in.-lb.). In like manner we can see that the second slab will be capable of resisting 3,000 lb. × 5½ in., or 16,500 in.-lb., so that although the area of the slabs is equal, the resisting moment is proportional to the distance at which each acts from the neutral axis. If this is clear, it will not be difficult to see that the theoretically fully-stressed beam would have a section as shown in *B*, and if the beam be made of this section, all parts of its would be stressed to the same amount. In other words, the ideal is to get the mass of material as far as possible from the neutral axis; and while this is not practicable in timber beams, it is actually done in steel beams, where we get heavy wide flanges and only thin webs.

To get the moment or measure of resistance of the equally-stressed beam is now a straightforward and simple task. The area of material (in the theoretical beam) on the top or compression side is breadth of beam × half the height of triangle *ABC* (see Fig. 14), or

$$\frac{\text{breadth}}{2} \times \tfrac{1}{2}\text{ depth of beam}$$

The arm at which this area acts is the distance of the centre of gravity from the neutral axis, which is ⅔ × ½ depth of beam. Multiplying area by leverage, we get breadth of beam × ¼ depth × ⅓ × depth of beam

$$= \frac{\text{breadth}}{1} \times \frac{1}{12} \times \frac{\text{depth}}{1} \times \frac{\text{depth}}{1}$$

On the tension or lower side there is an equal resistance. By adding the compression strength to the tensile strength we get the total modulus of resistance for a rectangular beam

$$Z = \left(\frac{1}{12} \times \frac{B \times D \times D}{1}\right) + \left(\frac{1}{12}\ \frac{B \times D \times D}{1}\right)$$

$$= \frac{1}{6}\ \frac{\quad \times D \times D}{1}$$

There only remains to multiply this modulus (or measure) of resistance by the strength of the material in order to find with what bending moment the beam can safely cope. For fir or northern pine the safe stress will be about 1,200 lb. to 1,400 lb. per sq. in. By writing the allowable stress per square inch as *f*, we can equate the bending moment against the modulus of resistance—

Bending moment = modulus × *f*,
or for a rectangular beam

$$\text{Bending moment} = \frac{B \times D \times D}{6} \times \frac{f}{1}$$

The modulus of resistance is given in Chapter III.

Table VIA gives the safe loads for wood beams when evenly loaded. The modulus of the sections is given so that a suitable section for a different kind of loaded beam may be found. Let us take, for example, a beam loaded with a point load of 2,000 lb. at 5 ft. from the left-hand support. If the beam spans over an opening of 20 ft., find a suitable section.

$$\text{Bending moment} = \frac{\text{load} \times 5 \times 15}{20}$$

$$= \frac{2{,}000 \times 5 \times 15}{20} = 7{,}500 \text{ ft.-lb.}$$

To reduce to in.-lb.

$$7{,}500 \times 12 = 90{,}000 \text{ in.-lb.}$$

$$\text{Modulus of resistance} = \frac{\text{Bending moment}}{\text{Safe stress}}$$

$$Z \text{ or modulus} = \frac{90{,}000}{1{,}200} = 75$$

A 10 in. × 4 in. beam has a modulus of 66, and a 10 in. × 6 in. a modulus of 100; so that a 10 in. × 5 in. beam with a modulus of 83 would do if one could be easily obtained.

The general principles for designing any kind of beam, whether wood, steel, cast iron or reinforced concrete, are similar; it is a case of finding the bending moment, the shearing forces (in

some cases, the deflection) and the resisting moment of the beam.

STEEL BEAM DESIGNING. In E and F two methods of stress distribution are shown. In E the section modulus of the total cross-section is used and is equated against the bending moment. This method is generally employed in structural designing offices. Some authorities argue that the web should be neglected so far as bending stresses are concerned; others go still further and say that only the horizontal part of the flange angles should be taken as capable of resisting bending stresses; and, again, there are others who allow a portion only of the web to assist the flanges. It is reasonably accurate and easy to work to if we take the whole area of the flange angles, and in order to get a value for the web plate between the angles, assume that the resistance is acting at the outside of the angles or the full depth of the beam. In this way we neglect the web, except the portion between the flange angles, the condition being something like the one shown in F. Two examples will show the way to work out the strength of a steel girder. What load concentrated in the centre could a beam made up of four angles 3 in. × 3 in. × ⅜ in. and a web 36 in. × ⅜ in. carry over a span of 20 ft.?

Here the bending moment would be

$$\frac{\text{Load} \times \text{Span}}{4}$$

Area of one flange is area of two angles 3 in. × 3 in. × ⅜ in., flange area = 2 × 2·1 = 4·2 sq. in.

Modulus of resistance

$$= f_s \times 4{\cdot}2 \times 36 \text{ in.}$$
$$= 7\tfrac{1}{2} \text{ tons} \times 151 = 1{,}130$$

therefore $\dfrac{\text{Load} \times \text{Span}}{4} = 1{,}130$ in.-tons

Transposing, we get

$$\text{Safe load} = \frac{1130 \times 4}{20 \times 12} = \text{say, 19 tons at centre}$$

If the load be evenly distributed over the span

$$\text{Bending moment} = \frac{\text{Load} \times \text{Span}}{8}$$

therefore $\dfrac{\text{Load} \times \text{Span}}{8} = 1{,}130$

$$\text{Safe load} = \frac{1130 \times 8}{20 \times 12} = \text{say, 38 tons}$$

Deflection Due to Longitudinal Stresses. For a stress fy, the material of length δx is stretched by an amount $fy \cdot \delta x \div E$ (see equation (4)).

The angle δi between the two faces DE and D_1E_1, in Fig. 13, as measured by its tangent or circular measure, equals $fy \cdot \delta x \div E \cdot y$.

A from equation (22) $Bx/I = fnt/nt = fy/y$,

$$\delta i = Bx \cdot \delta x \div E \cdot I \qquad . \quad . \quad (24)$$

TABLE VIA

TIMBER BEAMS (Good White Pine or Fir)

Calculated on the assumption of fs = 1,200 lb. per sq. in. (approx.)

Span in Feet	Section	In. 8 × 4	In. 8 × 6	In. 10 × 4	In. 10 × 6	In. 12 × 4	In. 12 × 6	In. 14 × 6	In. 14 × 8	In. 16 × 8	In. 18 × 10
	Modulus of Section	42	64	66	100	96	144	196	260	340	540
		Approximate Safe Distributed Load in Lb.									
8		4,000	6,000	6,500	9,700	9,500	14,200	19,600	26,000	34,000	54,000
9		3,600	5,400	5,900	8,800	8,600	12,900	18,400	24,400	31,900	50,600
10		3,200	4,800	5,200	7,800	7,600	11,400	17,200	22,800	29,800	47,200
11		2,900	4,400	4,800	7,200	7,000	10,500	16,000	21,200	27,700	43,800
12		2,600	3,900	4,300	6,400	6,300	9,400	14,700	19,500	25,500	40,500
13		2,400	3,600	4,000	6,000	5,900	8,900	13,500	17,900	23,400	37,100
14		2,200	3,300	3,700	5,500	5,400	8,100	12,300	16,300	21,300	33,700
15			3,100	3,500	5,200	5,100	7,600	11,000	14,700	19,200	30,300
16			2,900	3,200	4,800	4,700	7,000	9,800	13,000	17,000	27,000

***Note.* If beam carries load in centre of span it is only safe for half the load given in table.**

Shear Stresses in Cross-section. The total tension in the top portion PD of the section DE in Fig. 13, between two lines parallel to the neutral axis distances y and nt from it, is $\Sigma_y^{nt} by \cdot \delta y \cdot fy = Bx . \Sigma_y^{nt} by \cdot \delta y \cdot \frac{y}{I}$, as from equation (22), $fy = Bx \cdot y \div I$.

If the area moment about the neutral axis of the portion of the section, a distance y and nt

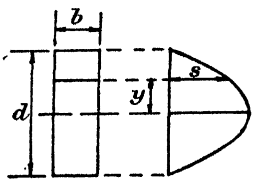


FIG. 15

from it, is written AM_y^{nt}, the expression for the total tension in PD becomes

$$(AM_y^{nt}) \times Bx \div I \quad . \quad . \quad . \quad (25)$$

If the bending moment at the section CF is $Bx + \delta Bx$, the total tension in the top portion QC of the section CF

$$= (AM_y^{nt}) \times (Bx + \delta Bx) \div I \quad . \quad (26)$$

From equations (25) and (26) $(AM^{n}_{t})\ (\delta Bx) \div I$ = difference in pull on sections QC and

$$PD = s \cdot by \cdot \delta x \quad . \quad . \quad . \quad (27)$$

as this difference must represent the total horizontal shear along the plane PQ and s, the vertical shear stress, has been shown (see Fig. 7A) to have the same value as the horizontal shear stress.

If the vertical shear S is constant throughout the length δx, the bending moment at CF must be greater than the bending moment at DE by an amount $S \cdot \delta x$, that is

$$S \cdot \delta x = \delta Bx \quad . \quad . \quad . \quad . \quad (28)$$

From equations (27) and (28), $\frac{S \cdot \delta x}{I} \cdot (AM_y^{nt})$ $= s \cdot by \cdot \delta x$; therefore

$$s = S \cdot (AM_y^{nt}) \div by \cdot I \quad . \quad . \quad (29)$$

For a rectangle of area $d \times b$, $s = S\left(b \cdot \frac{d}{2} \cdot \frac{d}{4} - b \cdot y \cdot \frac{y}{2}\right) \div b \cdot \frac{b \cdot d^3}{12}$; for $y = d/2$, $s = 0$; for $y = 0$, $s = \frac{3}{2} \cdot \frac{S}{b \cdot d}$; intermediate values being the ordinates of a parabola (see Fig. 15). As the average shear stress is $\frac{s}{b \cdot d}$, the maximum is 50 per cent more than the average.

For a rolled steel joist, if the average shear stress is calculated by dividing the total shear by the area of the web $(d \cdot t)$, the shear at the

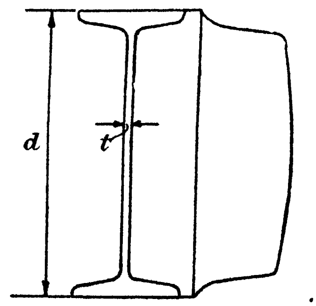


FIG. 16

top of the web by the fillet is approximately the same as the average, and the shear at the neutral axis is about one-eighth more than the average, the stress being distributed as indicated in Fig. 16.

Composite Beams. In members constructed of two materials, such as concrete and steel, if there is no relative movement of the two materials in contact, the unital strains must be identical; and therefore, from equation (5), the stresses must be directly proportional to their elastic moduli.

If m is the ratio of the elastic modulus of the stronger material to that of the weaker, for finding the area and other properties of the composite section, the stronger material may be considered as replaced by the weaker material of an area m times that of the stronger, acting as if condensed into the same space.

EXAMPLE.

A beam made of two steel plates and three timbers securely bolted together is to carry a uniformly distributed load of 15,000 lb. over a span of 24 ft. What would be a suitable size of beam?

Assuming the timbers to be fir, the safe stress per square inch may be taken at 1,200 lb. For mild steel plates the safe stress may be about seven tons per square inch, say, 15,000 lb.

If the beams and the steel flitch plates are securely bolted together, it follows that the deflection of the plates and the beams must be the same. The modulus of elasticity (which is the load that would stretch a beam to twice its length if the law of Hooke held good) for fir may be 1,500,000 lb., and for steel 30,000,000 lb.,

so that the maximum stress the timber can be called on to resist will be—

$$\frac{1{,}500{,}000}{30{,}000{,}000} \times \frac{15{,}000}{1} = 750 \text{ lb.}$$

against the safe stress of 1,200 lb. which would be allowable if the steel flitches were not used. Here we see at once a disadvantage in the steel plates between wood beams.

We will assume a beam composed of three timbers 4 in. by 14 in., and two plates ¾ in. by 14 in.

The strength of a timber beam to resist bending is given by the formula

$$= \frac{\text{breadth} \times \text{depth} \times \text{depth}}{6} \times \frac{\text{safe stress}}{12}$$

$$= 3 \times \frac{4 \times 14 \times 14 \times 750}{6 \times 12}$$

$$= 3 \times 8{,}160 = 24{,}500 \text{ ft.-lb.}$$

Strength of two steel plates

$$= \frac{\text{breadth} \times \text{depth} \times \text{depth}}{6} \times \frac{\text{safe stress}}{12}$$

$$= 2 \times \frac{\frac{3}{4} \times 14 \times 14 \times 15{,}000}{6 \times 12}$$

$$= 2 \times 30{,}625 = 61{,}250 \text{ ft.-lb.}$$

Total strength of beam = 24,500 + 61,250 = 85,750 ft.-lb. Actual bending moment on beam

$$= \frac{\text{load} \times \text{span in feet}}{8}$$

Assume weight of beam 1,500 lb

Then total load = 15,000 + 1,500 = 16,500 lb.

$$\text{Bending moment} = \frac{16{,}500 \times 25}{8} = 51{,}500 \text{ ft.-lb. (approx.)}$$

The assumed beam which is capable of resisting 85,750 ft.-lb. is too strong Let us try two plates ⅜ in. thick instead of ¾ in. thick. The strength to resist bending will be—

For the three timbers 4 in. × 14 in.	= 24,500 ft.-lb.
For two plates ⅜ in. × 14 in. (½ × 61,250) . . .	= 30,625 ft.-lb.
	55,125 ft.-lb.

This section will do nicely, and with a depth of beam which is $\frac{1}{21}$ of the span and the timber only stressed to 750 lb. per sq. in., the deflection will not be excessive.

For concrete the elastic modulus is a variable and uncertain quantity, but as a basis for calculation it is usual to assume that m is constant and equals 15 for the mixture most commonly specified. As concrete is comparatively weak in tension, it is usual also to neglect its tension value entirely, and take all the tension in the steel.

If a steel joist of depth d, area As, and moment of inertia Is, is embedded in a slab of concrete of area $D \times b$ (see Fig. 17), and n is the distance of the centroid of the composite section from the top compressed edge, then

$$b \cdot n \cdot n/2 = m \cdot As \cdot (D - n - d/2) \quad . \quad (32)$$

that is, $b \cdot n^2 + 2n \cdot m \cdot As = 2\,(D - d/2) \cdot m \cdot As.$

Dividing throughout by $b \cdot D$ and calling $\frac{m \cdot As}{b \cdot D} = r$, and $n/D = n_l$, the equation becomes

$n_l^2 + 2n_l \cdot r = (2 - d_l) \cdot r$; therefore

$$n_l = \sqrt{r^2 + r \cdot (2 - d_l)} - r$$
$$= \sqrt{r \cdot (r + 2 - d_l)} - r \quad . \quad . \quad (33)$$

The moment of inertia of the composite section is

$$I = \frac{bn^3}{3} + m \cdot Is + m \cdot As \cdot (D - n - \tfrac{1}{2}d)^2 \quad (34)$$

The section modulus Mc for concrete equals $I \div n$. For steel the section modulus $Mt = I \div m \cdot (D - n)$.

If the top of the joist lies above the neutral axis, the concrete area is reduced by the area

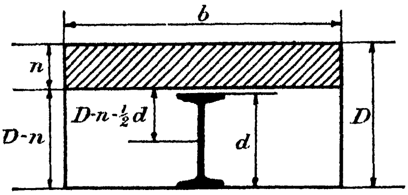


FIG. 17

displaced by the steel, but the nature of the assumptions made do not justify any further refinement in the formulae.

If the joist is replaced by rods, and if D is measured to the centre of the rods, Is and d may be neglected and equation (33) becomes

$$n_l = \sqrt{r\,(r + 2)} - r \quad . \quad . \quad (35)$$

Then equation (34) becomes

$$I = \tfrac{1}{3}b \cdot n^3 + m \cdot As \cdot (D - n)^2 \quad . \quad (36)$$

If the allowable concrete stress is fc, and the allowable steel stress is ft (connected by the relationship $m \cdot fc/n = ft/(D - n)$), the bending moment the section can resist has two values

$$Rc = I \cdot fc/n \text{ and } Rt = I \cdot ft/m \cdot (D - n) \quad (37)$$

of which the smaller value must be taken.

From equations (36) and (37)

$$Rc = \{\tfrac{1}{3}b \cdot n^3 + m \cdot As \cdot (D - n)^2\} \cdot fc/n \quad (38)$$

As from equation (32) $\tfrac{1}{2} \cdot b \cdot n^2 = m \cdot As \cdot (D - n)$

$$Rc = \{\tfrac{1}{3}b \cdot n^2 + \tfrac{1}{2}b \cdot n \cdot (D - n)\} \cdot fc$$
$$= \tfrac{1}{2} \cdot b \cdot n \cdot fc\,(D - \tfrac{1}{3}n) \quad . \quad . \quad . \quad (39)$$

As the distance from the neutral axis of the centre of action of the compression has been shown (see equation (22), etc.) to equal (I of compression area about the neutral axis) $\div$ (area moment of the same area about the same axis), this distance equals $\frac{1}{3}b \cdot n^3 \div \frac{1}{2}b \cdot n^2 = \frac{2}{3}n$. This is also obvious from the fact that the centroid of a triangle is two-thirds the height from the apex.

The lever arm is thus $(D - \frac{1}{3}n)$. As the total compression is $\frac{1}{2}b \cdot n \cdot fc$, Rc is obviously $\frac{1}{2}b \cdot n \cdot fc\ (D - \frac{1}{3}n)$, the result obtained another way in equation (39).

Similarly,

$$Rt = As \times ft \cdot (D - \tfrac{1}{3}n) \qquad . \qquad . \quad (40)$$

EXAMPLE 1. A 5 in. $\times$ 3 in. rolled steel joist (R.S.J.) has the following properties: $As = 3{\cdot}24$ in.^{2}, $Is = 13{\cdot}6$ in.^{4}

If in Fig. 17, $b = 24$ in., $D = 5$ in., and the stresses are limited to $fc = 600$ lb. per sq. in., and $ft = 18{,}000$ lb. per sq. in., find the resistance moment, assuming $m = 15$.

SOLUTION.

$$r = m \cdot As \div b \cdot d = 15 \times 3{\cdot}24 \div 24 \times 5 = {\cdot}405$$
$$n_, = \sqrt{({\cdot}405 \times 1{\cdot}405)} - {\cdot}405 = {\cdot}754 - {\cdot}405 = {\cdot}349$$
$$n = n_l \cdot d = {\cdot}349 \times 5 = 1{\cdot}745,\ D - \tfrac{1}{2}d = 2{\cdot}5$$
$$D - \tfrac{1}{2}d - n = {\cdot}755,\ D - n = 3{\cdot}255$$
$$I = \tfrac{1}{3} \times 24 \times 1{\cdot}745^3 + 15 \times 13{\cdot}6 + 15 \times 3{\cdot}24 \times {\cdot}755$$
$$= 42{\cdot}5 + 204 + 27{\cdot}7 = 274{\cdot}2$$
$$Rc = 600 \times 274{\cdot}2 \div 1{\cdot}745 = 94{,}200 \text{ in.-lb.}$$
$$Rt = 18{,}000 \times 274{\cdot}2 \div 15 \times 3{\cdot}258 = 101{,}000 \text{ in.-lb.}$$
R of joist alone
$$= 18{,}000 \times 13{\cdot}6 \div 2\tfrac{1}{2} = 98{,}000 \text{ in.-lb.}$$

The R of joist alone is greater than Rc. It would not be reasonable, however, to take a lower safe load on that account.

In practice, owing to the stiffening effect of the concrete on the compression flange of the joist, it is usual to calculate the resistance moment of a floor of joists with a filling of sound concrete as if the joists acted independently of the concrete, and were stressed to, say, 9 tons per sq. in. The stress in the concrete would then be

$$\frac{9}{8} \times \frac{98{,}000}{94{,}200} \times 600 = 700 \text{ lb. per sq. in.}$$

EXAMPLE 2. What is the effect of increasing the total depth from 5 in. to 7 in.?

SOLUTION.

$$r = 15 \times 3{\cdot}24 \div 24 \times 7 = {\cdot}289$$
$$d_l = 5 \div 7 = {\cdot}714$$
$$n_l = \sqrt{(289 \times 1{\cdot}575)} - {\cdot}289 = {\cdot}675 - {\cdot}289 = {\cdot}386$$
$$n = {\cdot}386 \times 7 = 2{\cdot}70$$
$$D - \tfrac{1}{2}d = 4{\cdot}5$$
$$D - \tfrac{1}{2}d - n = 1{\cdot}80,\ D - n = 4{\cdot}3$$
$$I = \tfrac{1}{3} \times 24 \times 2{\cdot}70^3 + 15 \times 13{\cdot}6 + 15 \times 3{\cdot}24 \times 1{\cdot}80^2$$
$$= 157{\cdot}4 + 204 + 157{\cdot}4 = 518{\cdot}8$$
$$Rc = 600 \times 518{\cdot}8 \div 2{\cdot}70 = 115{,}000 \text{ in.-lb.}$$
$$Rt = 18{,}000 \times 518{\cdot}8 \div 15 \times 4{\cdot}3 = 144{,}500 \text{ in.-lb.}$$

This is nearly 50 per cent more than the R of joist alone, so that in this case there is justification for a rule sometimes adopted of calculating as if the joist acted alone with a stress of 10 tons per sq. in., if there is 1 in. cover of concrete to the top flange, and 11 tons per sq. in. if there is 2 in. cover, only if the concrete can safely be stressed to

$$\frac{11}{8} \times \frac{98{,}000}{115{,}000} \times 600 = 700 \text{ lb. per sq. in.}$$

DEFLECTION OF BEAMS

Cantilever Point Load. Consider a cantilever beam of length l supported at R and carrying a single load W a distance a from the support.

At the present neglect considerations of the weight of the beam itself, and the distribution of concentrated loading at the points of application and support.

At every point between the load and the support there is the same vertical load W producing shear stresses; the value of the shear is thus constant and equals W. To the right of the load the cantilever beam is not stressed, and the shear is zero. This is indicated graphically in the shear diagram of Fig. 18, where the horizontal line represents the length of the beam to some convenient scale, and vertical lines represent the shear to another scale.

At any point a distance x from W, the bending moment $(Bx) = W \cdot x$, which may be represented by a vertical line in the bending moment diagram of Fig. 18, drawn to a suitable scale. The ends of all such vertical lines lie on a sloping line, whose vertical distance from the base line is zero under the load, and $W \cdot a$ at R.

The tangent of the slope of this line is $W \cdot a \div a = W =$ the vertical shear in the part of the beam considered.

Referring back to equation (28), where it was shown that $S = \delta Ba \div \delta x$, it will be seen that it is universally true that *the tangent of the slope of the bending moment diagram at any point equals the vertical shear at that point.* . . (41)

This important truth can be readily appreciated from the fact (as was shown for Fig. 7A) that a shear, due to a load on the right of a section, tending to produce clockwise rotation in an element of the cantilever, must cause a pull in the top flange and a push in the bottom flange to establish equilibrium. If the shear is constant, and the flanges are parallel, the pull and push must increase uniformly along the cantilever, and with a constant lever arm the bending moment must also increase uniformly.

This increase in pull (or push) Professor Claxton Fidler used to liken to the increase in

the tension on a rope, used in a tug-of-war, as each man added his share of the pull, but in this case the increase is in steps, as will be shown later for a trussed girder, and not continuous as in the cantilever with a point load.

Elastic Curve. Tension in the top of the cantilever, and compression in the bottom, will

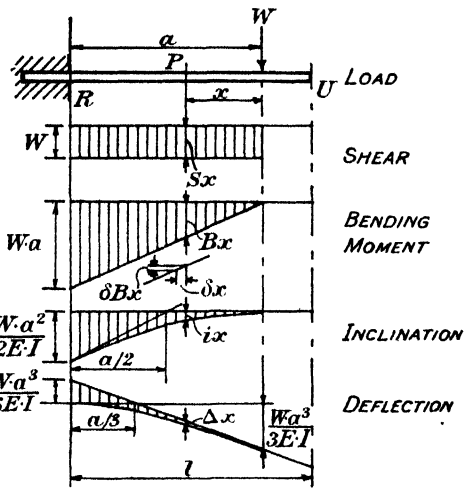


FIG. 18

cause the beam to bend, with its top portion convex like a hog's back. This bending moment is described as *hogging* moment, as distinguished from the *sagging* moment, which causes a beam supported at each end to bend with its top portion concave. The curve of the deflected neutral axis is known as the *elastic curve*.

From equation (24), it is seen that δi (the change of inclination in the length δx) $= Bx \cdot \delta x \div E \cdot I$; from which it is obvious that the radius of curvature (which from Fig. 19 is seen to be $\delta x \div \delta i$, as $\delta x \div$ radius of curvature $= \delta i$) varies directly with the strength of the material (as measured by E), and the stiffness of the section (as measured by I).

The expression $Bx \cdot \delta x$ is the area of a small element of the bending moment diagram, so that, if I is constant for the length considered, ***the total inclination between tangents to the elastic curve at any two points equals the area of the bending moment diagram between them divided by E · I*** . . . . (42)

Deflection. It is, however, the linear vertical deflection that is usually required, and this may also be readily obtained from the same area as follows. If a series of tangents are drawn to the elastic curve, to meet the vertical at any point P, the portion of the vertical intercepted between the tangent drawn at the extremities of a portion of the curve δz apart (see Fig. 20) will be $z \cdot \delta i \div \cos^2 \theta$, where z is the distance of the element of the curve from the vertical through P and θ is the inclination of the tangent to the initial horizontal direction.

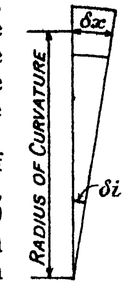


FIG. 19

In the figure the curvature of the elastic curve is exaggerated, but in practice it is so slight that θ is very small, $\cos^2 \theta = 1$ and $z \cdot \delta i \div \cos^2 \theta = z \cdot \delta i$. From equation (28), $z \quad \delta i = z \cdot Bx \cdot \delta z \div E \cdot I =$ moment about P of the area of the bending moment diagram with base δz, divided by $E \cdot I$.

The sum of all such small intercepts is Δx, which, therefore, *equals the moment about P of*

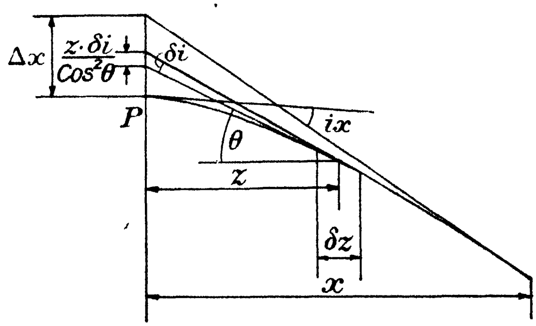


FIG. 20

the area of the bending moment diagram with base x, divided by E · I . . . . (43)

For a point load, $E \cdot I \cdot \Delta x = W \cdot x \times \frac{1}{2}x \times \frac{2}{3}x = W \cdot x^3 \div 6$.

The deflection considered is that due to longitudinal stresses. That due to shear, and also the effect of a variable I, will be discussed later.

Connection Between $W.S.B.i$ and Δ Diagrams. It will be noted that Bx, in Fig. 18, $= W \cdot x =$ area of shear diagram below x, and $E \cdot I \cdot ix = W \cdot x^2/2 =$ area of bending moment diagram below x. Similarly, Δx equals the corresponding area of the inclination diagram. There is thus the following series of values: $Sx = W$, $Bx = W \cdot x$, $E \cdot I \cdot ix = W \cdot x^2/2$, $E \cdot I \cdot \Delta x = W \cdot x^3/2 \times 3$.

If the load is uniformly distributed (see Fig. 21), the corresponding series is load $= w$, $Sx = w \cdot x$, $Bx = w \cdot x^2/2$, $E \cdot I \cdot ix = W \cdot x^3/2 \times 3$, and $E \cdot I \cdot \Delta x = w \cdot x^4/2 \times 3 \times 4$.

If the load increases uniformly (see Fig. 22) the series is load $= k \cdot x$, $Sx = k \cdot x^2/2$, $Bx = k \cdot x^3/2 \times 3$, $E \cdot I \cdot ix = k \cdot x^4/2 \times 3 \times 4$, and $E \cdot I \cdot \Delta x = k \cdot x^5/2 \times 3 \times 4 \times 5$.

In each case, any one value is proportional to the area of the previous corresponding dia-

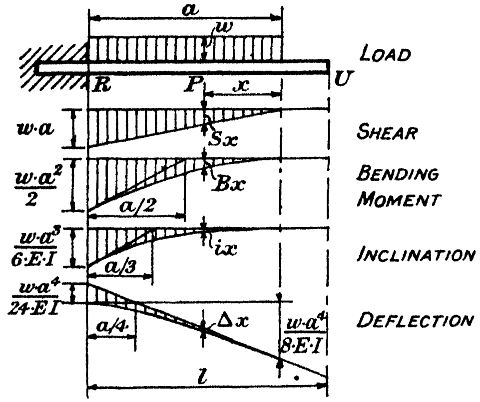


FIG. 21

gram below x, and to the tangent to the slope of the curve in the subsequent corresponding diagram, a distance x from the end of the load.

Thus the bending moment diagram bears the same relation to the load diagram that the deflection diagram does to the bending moment diagram, and *the deflection diagram can be drawn as the bending moment diagram of the bending moment diagram.*

In regard to Figs. 18, 21, and 22, it will be observed that the tangent at the reaction end of the bending moment curve intersects the horizontal line of length a at the end for a point load, at the centre for a uniformly distributed load, and at the third point for a triangular load, in each case *vertically below the centroid of the load.*

Parabola. If the load distribution had been parabolic, as shown for the bending moment diagram in Fig. 21, or the shear diagram in Fig. 22, the tangent of the reaction end of the bending moment curve would have been $a/4$ from the reaction; from which it may rightly be inferred that the centroid of a parabolic triangle (with concave "hypotenuse") is one-quarter the length from the vertical side, as shown in Fig. 23. Fig. 23 also shows a simple construction for finding a point P half-way between two verticals through P_1 and P_2, the points of contact of tangents to the curve.

If the two tangents UP_1 and UP_2 are bisected in T_1 and T_2, the line T_1T_2 is, at P, tangential to the curve vertically below U. P also bisects the vertical from U to the chord P_1P_2. The construction, though shown for a particular case, is of universal application, as was shown in *Concrete and Constructional Engineering*, for July, 1926.

As for the parabolic shear distribution of

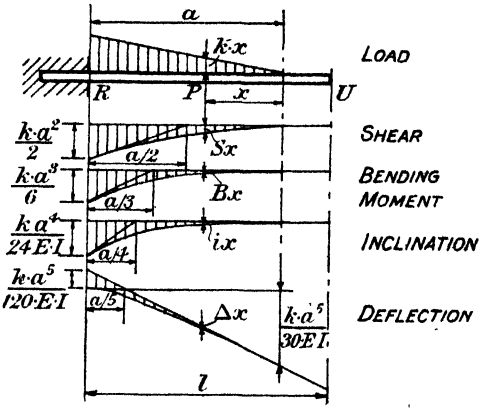


FIG. 22

Fig. 22, the bending moment = end shear $\times\ a/3$, it may rightly be inferred that the area of a parabolic triangle, with a concave hypotenuse, is one-third of the product of base and height, and therefore the area of a parabolic triangle, with a convex hypotenuse, is the remaining

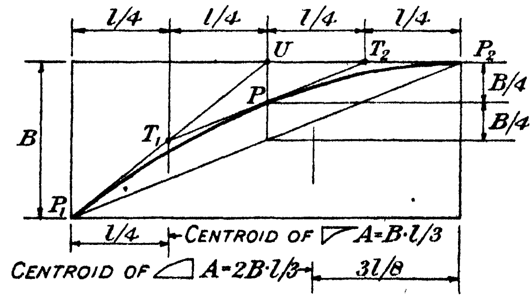


FIG. 23

two-thirds of the enclosing rectangle. The distance from the apex of the centroid of the latter triangle is five-eighths of the side.

Free-end Deflections. The value of Δx, deduced above, is the vertical distance between the point considered and a tangent drawn to the elastic curve at the free end. The vertical distance of the free end from the tangent at the fixed end can be obtained from this, as the point of intersection of the two tangents is known and shown in Figs. 18, 21, and 22.

The deflection of the point at the end of the load is thus $2 \times W \cdot a^3 \div 6E \cdot I = W \cdot a^3 \div$

$3EI$ for a point load, $3 \times w \cdot a^4 \div 24E \cdot I = W \cdot a^4 \div 8E \cdot I$ for a uniformly distributed load, and $4 \times k \cdot a^5 \div 120E \cdot I = k \cdot a^5 \div 30E \cdot I$ for a uniformly increasing load; the deflection curve is thus completely determined.

The free-end deflection can also be obtained directly by applying equation (43); for example, in Fig. 21, the area of the parabolic triangle of the B diagram $= \frac{1}{3} \times \frac{w \cdot a^2}{2} \times a = w \cdot a^3 \div 6$. The centroid is $\frac{3}{4}a$ from the free end of the load. The deflection at the free end is thus equal to $\frac{w \cdot a^3}{6} \times \frac{3a}{4} \div EI = w \cdot a^4 \div 8E\ I$.

Propped Cantilever. If an upward thrust is applied to the end of the cantilever shown in

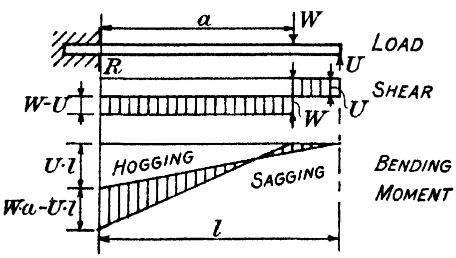


FIG. 24

Fig. 18, either by a prop or a rope over a pulley, there will be an upward shear in the beam between the points U and W. If this upward thrust equals U, it will decrease the downward shear between the point load and the reaction from W to $W - U$, and the shear diagram will be as shown in Fig. 24. The load U will cause a sagging bending moment, which will reduce the hogging moment at R from $W \cdot a$ to $W \cdot a - U \cdot l$, and the bending moment diagram will be as shown in Fig. 24.

Simple Beams. If $W \cdot a = U \cdot l$, the bending moment at R is zero, and the diagram shown in Fig. 25 is that for a point load on a beam freely supported at the ends. The bending moment diagram is usually drawn with the base line horizontal, as shown at the bottom of the figure.

The end shear is $U = W \cdot a \div l$, and the maximum moment under the point load is B max. $= W \cdot a \cdot (l - a) \div l$.

For the uniformly distributed load, shown in Fig. 21, the value of U to neutralize the end moment at R is $U = \frac{1}{2}w \cdot a^2 \div l$, and the shear and bending moment diagrams are as in Fig. 26.

The bending moment is seen to be a maximum when the slope of the curve, and therefore the shear (see also equation (41)), is zero.

If $l = a$, $U = R = w \cdot l/2$, and the maximum B is at the centre. The moment at any point x from the end U is the difference between the

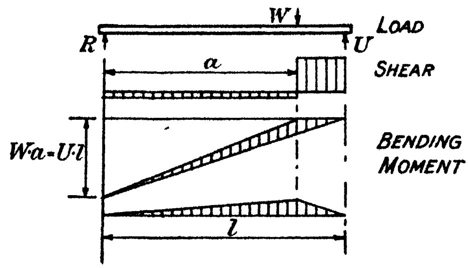


FIG. 25

cantilever moments of the end reaction U, with lever arm x, and the distributed load $w \cdot x$ with lever arm $x/2$; that is, $Bx = \frac{1}{2}w \cdot l \times x - w \cdot x \times \frac{1}{2}x = \frac{1}{2}w \cdot x \cdot (l - x)$. When $x = \frac{1}{2}l$, B max. $= w \cdot l^2/8$.

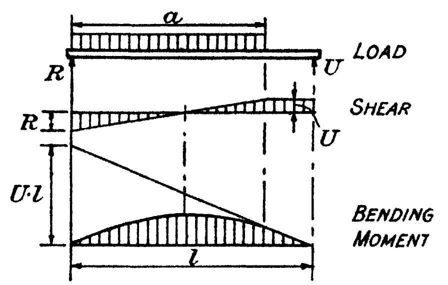


FIG. 26

Beam with Any Loading. When the loads to be carried by a girder are known, an assumption has to be made as to the weight of the girder itself. This is best done after the approximate size of the girder required by the loads is known. Usually, the loads to be carried can be only rough approximations; so that except in the case of girders of large span, when the dead load may be a large proportion of the total load, meticulous accuracy in the weight of the girder itself is not necessary for purposes of stress calculation.

The loads to be carried may usually be regarded as uniformly distributed. Concentrated, or point loads, and also end reactions, may be regarded as uniformly distributed over a short length of girder. Consider a girder of clear span $l_1 + l_2 + l_3 + l_4 + l_5$ ft., each part with loads w_1, w_2, w_3, w_4, and w_5 tons per foot run, respectively. See Fig. 27.

If the bearing lengths are *bo* and *bn*, and the loads on the supports are uniformly distributed, the centres of the reactions *Rl* and *Rr* will be the clear span $+ \frac{1}{2}bo + \frac{1}{2}bn = l$ ft. apart.

The calculations to determine *Rr* are best set

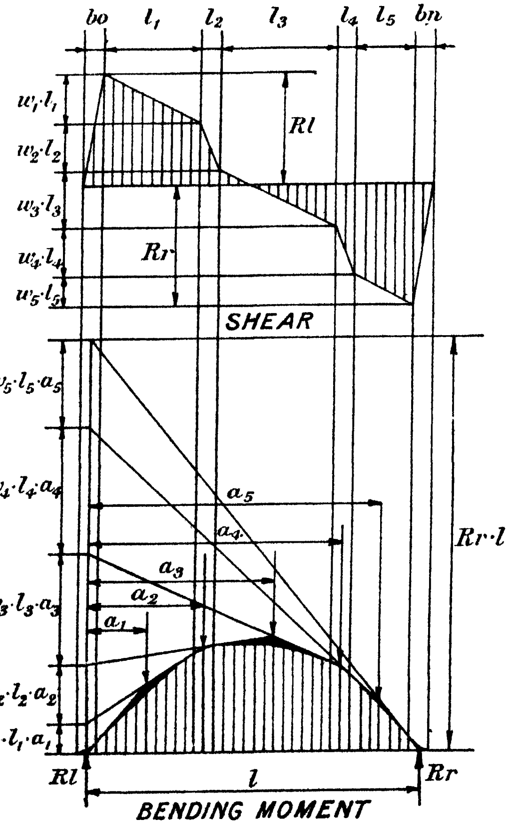


FIG. 27

out as shown, the various columns giving—

1. The length in feet of each part of the girder;
2. The loading in tons per foot run on each part;
3. The total load in tons on each part, that is, the product of the items in columns 1 and 2;
4. The distance in feet of the centre of gravity of the load in column 3 from the centre of the left reaction;
5. The cantilever moment in foot-tons of the load in column 3 about the centre of the left reaction, that is, the product of the items in columns 3 and 4.

1	2	3	4	5
l_1	w_1	$w_1 \cdot l_1$	$\frac{1}{2}bo + \frac{1}{2}l_1 = a_1$	$w_1 \cdot l_1 \cdot a_1$
l_2	w_2	$w_2 \cdot l_2$	$\frac{1}{2}bo + l_1 + \frac{1}{2}l_2 = a_2$	$w_2 \cdot l_2 \cdot a_2$
l_3	w_3	$w_3 \cdot l_3$	$2bo + l_1 + l_2 + \frac{1}{2}l_3 = a_3$	$w_3 \cdot l_3 \cdot a_3$
l_4	w_4	$w_4 \cdot l_4$	$\frac{1}{2}bo + l_1 + l_3 + l_3 + \frac{1}{2}l_4 = a_4$	$w_4 \cdot l_4 \cdot a_4$
l_5	w_5	$w_5 \cdot l_5$	$\frac{1}{2}bo + l_1 + l_2 + l_3 + l_4 + \frac{1}{2}l_5 = a_5$	$w_5 \cdot l_5 \cdot a_5$
Sum 1		*Sum* 3		*Sum* 5

The sum of the items in column 1 is the clear span; that in column 3 is the total load on the clear span; that in column 5 is the total clock-

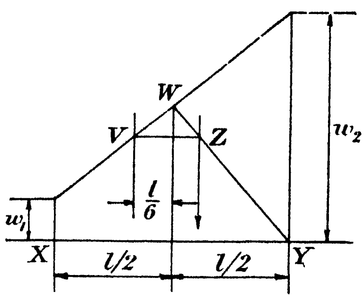


FIG. 28

wise moment of the loads about the centre of the left reaction.

This must be neutralized by the counter-clockwise moment due to *Rr*; therefore, $Rr =$ sum $5 \div l$; also, $Rl =$ sum $3 - Rr$.

From the calculations so made, the complete shear and bending moment diagrams can be constructed, as shown in Fig. 27, by setting out the items in columns 3 and 5 on a vertical line through the centre of the left reaction.

The further construction of the shear diagram is clear from the figure. The bending moment diagram is constructed by joining the centre of the right reaction to the top of the line representing $w_5 \cdot l_5 \cdot a_5$. From the point where this line cuts the vertical through the centre of gravity of $w_5 \cdot l_5$, a line is drawn to the bottom of the length representing $w_5 \cdot l_5 \cdot a_5$.

From the point where this line cuts the vertical through the centre of gravity of $w_4 \cdot l_4$, a line is drawn to the bottom of the vertical representing $w_4 \cdot l_4 \cdot a_4$, and so on. The straight line outline at the bottom of the diagram is the moment diagram for point loads of values given in column 3, at the distances from the left reaction given in column 4.

The diagram is completed by drawing parabolic arcs in the widths l_1, l_2, etc., to touch the

inclined straight lines at their ends. The bending moments are thereby reduced in the span and increased over the supports, by the amounts shown black in the diagram.

If the load on any length increases uniformly, its centre of gravity can be found from the construction shown in Fig. 28. Join W, the extremity of the central vertical representing the average weight per foot run, to Y, the more heavily loaded end of the length considered. From V, on the load diagram line at a distance $l/6$ from the centre, draw a horizontal to cut WY in Z.

Then the centroid of the trapezium is in the vertical through Z.

Vertical Deflection of Beams due to Bending Stresses. The deflection of beams can be found by calculation. Using the formula

$$\frac{M}{I} = \frac{E}{R} \qquad (1)$$

where E = Modulus of elasticity
R = Radius of curvature
I = Moment of inertia
M = Bending moment

from (1) it is easy to see that

$$\frac{I}{R} = \frac{M}{EI} \qquad (2)$$

It can be shown that the radius of a curve is

$$R = \frac{\left\{1 + \frac{dy^2}{dx}\right\}\frac{3}{2}}{\frac{d^2y}{dx^2}}$$

from which $\frac{I}{R} = \frac{\frac{d^2y}{dx^2}}{\left\{1 + \frac{dy^2}{dx}\right\}\frac{3}{2}}$

The deflection in beams is small and the slope of the deflection $\frac{dy}{dx}$ is small, so that $\frac{dy^2}{dx}$ will be so small that it can be neglected.

We can then write $\frac{I}{R} = \frac{d^2y}{dx^2}$

and from (2) it follows $\frac{d^2y}{dx^2} = \frac{M}{EI}$

from which the general expression comes to

$$EI\frac{d^2y}{dx^2} = M$$

$$EI\frac{dy}{dx} = \int M dx$$

Slope of beam is $\frac{dy}{dx}$

Therefore if y is the deflection we get

$$EIy = \iint M dx dx$$

Table VIB shows six cases of beams often met with, and the corresponding bending moment curves and stress force diagrams. The values of maximum bending moment and maximum stressing forces are given. Notice that in the deflection column the constant is WL^3EI. For each condition this has to be multiplied by a value which is indicated. In all the cases shown it is assumed that the cross-section of the beam is the same for the whole length. It follows that the moment of inertia will not vary. (In the case of plate girders the moment of inertia often varies due to the change of flange plate area.) In the paragraph on Deflection, page 1421, the proof of the deflection due to longitudinal stresses is given. Stated in other terms, we can say the deflection of a beam can be found by considering the beam to be loaded with the value of the bending moment curve and the result divided by $E \cdot 1$. An example will make this clear.

EXAMPLE.

Find the formula for the deflection of a beam simply supported at both ends, and loaded at the centre (Case 3, Table VIB).

It is clear that the shape of the bending moment diagram is a triangle and that maximum value is at centre of span $WL/4$. Area of a triangle is Base × Length/2.

In this case height is $WL/4$ and base is the Span L. Area of bending moment diagram will be

$$L \times \frac{WL}{4} \times \frac{1}{2} = \frac{WL^2}{8}$$

Now consider the beam is loaded with this amount. At the ends of the beam the value is nil and is at maximum at the middle of the beam. The centre of gravity of the load (triangle) will be one-third of half span from the centre. The triangle on the left of the centre line has an area of

$\frac{1}{2} \times \frac{WL^2}{8}$ and its centre of gravity is $\frac{1}{3} \times \frac{L}{2}$

from the beam centre. Now find the value at the beam centre.

Reaction at left hand $= \frac{WL^2}{16}$

Its lever arm from the centre of beam is $\frac{L}{2}$

Moment of reaction $= \frac{WL^2}{16} \times \frac{L}{2}$

Moment of triangle load on left-hand side of centre line

$$\text{Amount is } \frac{1}{2} \times \frac{WL^2}{8} = \frac{WL^2}{16}$$

$$\text{Lever arm is } \frac{1}{3} \times \frac{L}{2} = \frac{L}{6}$$

$$\text{Moment is therefore } \frac{WL^2}{16} \times \frac{L}{6} = \frac{WL^3}{96}$$

Remember the bending moment at any point is the algebraic sum of all the moments on *either* side (not both sides) of the point considered.

Now reaction × arm is clockwise.

$$\text{Triangle} \times \frac{1}{3} \times \frac{L}{2} \text{ is anticlockwise.}$$

$$= \left(\frac{W \times L}{16} \times \frac{L}{2}\right) - \left(\frac{WL}{16} \times \frac{L}{6}\right)$$

$$= \frac{WL^3}{32} - \frac{WL^3}{96} = \frac{2WL^3}{96} = \frac{1}{48}\frac{WL^3}{1}$$

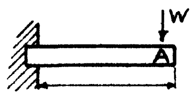
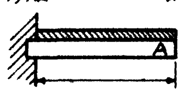
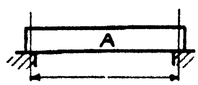
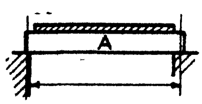
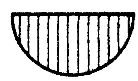
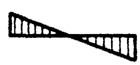
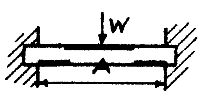
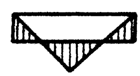
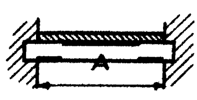
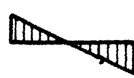
This value divided by $E\text{I}$ will give the deflection at the centre.

$$D = \frac{1}{48}\frac{WL^3}{E.\text{I}.} \quad \text{(as shown in table)}$$

Cases (5) and (6) where the beams have fixed ends can be dealt with by assuming the two end parts which are fixed at the supports to act as cantilevers supporting the middle part of the beam. The length of the middle part is determined by the point of contra-flexure (the place the bending moment is nil crosses the base line). For a beam with fixed ends and a load in the centre (case 5), the point of contra-flexure (change of bending) is at one-quarter of the span L from each support.

Where the ends are fixed and the load uniformly spaced, case (6), the points of contra-flexure at ·211L from each end.

TABLE VIB

	CONDITIONS OF SUPPORT & LOADING	BENDING MOMENT (MAX) INCH-TONS	SHEARING FORCE (MAX) TONS	BENDING MOMENT (DIAGRAM) INCH-TONS	SHEARING FORCE (DIAGRAM) TONS	DEFLECTION AT A (MAX) INCHES
1		$W \times L$	W			$\frac{1}{3}\frac{WL^3}{EI}$
2		$\frac{W \times L}{2}$	W			$\frac{1}{8}\frac{WL^3}{EI}$
3		$\frac{W \times L}{4}$	$\frac{W}{2}$			$\frac{1}{48}\frac{WL^3}{EI}$
4		$\frac{W \times L}{8}$	$\frac{W}{2}$			$\frac{5}{384}\frac{WL^3}{EI}$
5		$\frac{W \times L}{8}$	$\frac{W}{2}$			$\frac{1}{192}\frac{WL^3}{EI}$
6		$\frac{W \times L}{12}$	$\frac{W}{2}$			$\frac{1}{384}\frac{WL^3}{EI}$

Chapter V—MATERIALS OF CONSTRUCTION, PROPERTIES AND STRESSES

In building construction in the past, wall thicknesses, sizes of beams, columns, etc., were largely a matter of custom based on experience of what had proved satisfactory. This is often true at present. But with increased knowledge of the theory of stresses, and with improvement in methods of testing, past experience has been placed on a more rational basis, and calculations play an increasing part in design.

This has largely been brought about by economic necessity and increasing competition tending to eliminate wasteful use of material.

An engineer has been defined as one who "can do for £1 what anybody can do for £2," but before the most economic use can be made of materials available, it is essential to have knowledge of their behaviour.

Working Stresses and Factors of Safety

From tests it is possible to determine the stresses causing failure of a particular material. From these the stresses to be used in design, termed the *working stresses*, are chosen.

With a material which can be relied upon to show constant results in a testing machine, the working stress can be a larger proportion of the *ultimate stress*, or the stress causing failure, than for a material with wide variation in its behaviour.

The figure by which the ultimate stress is divided to determine the working stress is termed the *factor of safety*. As will be seen later, the value of this factor varies considerably.

Economic necessity has resulted in a gradual decrease in this factor.

If provision could be made for every contingency, and there were exact knowledge of the behaviour of the material, a structure could be safely built with a factor of safety a little greater than unity; but, as has already been pointed out in the discussion on loads, allowance has to be made for ignorance, and the factor of safety has sometimes been defined as a factor of ignorance. For Dead Loads use Table VIII; for Live Loads use Table VII.

The design stresses are often varied with the conditions of loading. The following table gives the factors of safety suggested by Professor Unwin—

TABLE VII

FACTORS OF SAFETY

Kind of Loading	Cast Iron	Wrought Iron and Steel	Timber	Masonry and Brickwork
Varying load—				
Stress of one kind only .	6	5	10	30
Reversed stresses .	10	8	15	
Shock loads .	15	12	20	

TABLE VIII.

Material	Transverse		Tension		Compression		Shearing		Bearing		Factor of Safety	Young's Modulus E	Remarks
	Ult.	Safe	Ult.	Safe	Ult.	Safe	Ult.	Safe	Ult.	Safe			
Timber	lb./sq. in.		lb./sq. in.		lb./sq. in.		lb./sq. in.		lb./sq. in.			lb./sq. in.	
Oak . .	10,000	1,650	10,000	1,600	7,500	1,250	3,000	600	—	—	6	1,200,000	Shearing
Pitch pine .	11,000	1,800	6,000	1,000	5,000	800	1,250	250	—	—	6	1,200,000	stress is
Fir . .	6,000	1,000	6,500	1,100	5,000	800	1,000	200	—	—	6	1,400,000	across grain.
Larch . .	5,000	800	9,000	1,500	3,000	500	1,000	200	—	—	6	900,000	
Iron	tons/sq. in.		tons/sq. in.		tons/sq. in.		tons/sq. in.		tons/sq. in.			tons/sq. in.	
Cast iron .	18	4½	10	1½	40	7	5	2½	32	8	4 to 6	8,200	
Wrot. iron .	20	5	24	5	18	4	20	4	24	5	4 to 5	13,000	
Steel . .	30	7½	30	7½	30	7½	24	5	30	8	4	13,400	
Portland Cement Concrete	tons/sq. ft.				tons/sq. ft.								Factor of safety for
Concrete 6 to 1	156	31			100	20					5		concrete
8 to 1	120	24			76	15					5		depends on
10 to 1	60	12			54	11					5		workmanship.

Another way of attaining the same end is to keep to one design stress and increase the varying, or live load, by an impact factor, the

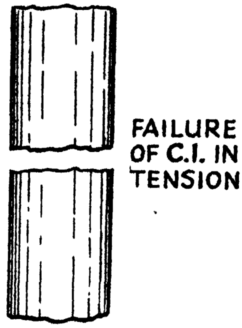


FIG. 29A

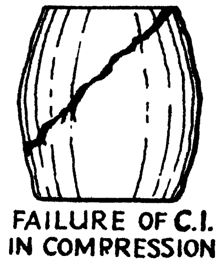


FIG. 29B

suitable value for which is very debatable, as has already been pointed out on page 1401.

IRON AND STEEL

Though the structural engineer as such need not concern himself with the composition and methods of manufacture of iron and steel, the following notes may be of interest to the student.

FIG. 29C

FIG 29D

Pig-iron. The ores from which iron is obtained consist of oxides and carbonates of iron, mixed with various impurities.

By the rapid combustion in a blast furnace of coke, or coal, mixed with the ore and limestone, iron is obtained in a liquid state. In this process of *smelting*, many of the impurities are removed in the *slag*, which itself is fluid at the high temperature attained, and separates from the liquid iron; the latter is either run into sand moulds, and allowed to cool as *pigs*, or used hot for further treatment.

Cast Iron. Pig-iron mixed with scrap castings and coke is treated in another blast furnace, and the resulting liquid iron is run into moulds formed in sand, the moulds being of such a size that the casting shrunk in cooling is of the required dimensions.

Cast iron is a brittle material much stronger in compression than in tension, so that when it was used for beams (a practice now abandoned) they were cast with their top, or compression, flanges much smaller than their bottom, or tension, flanges.

B.E.S.A. 153 does not specify the composition of the strong grey cast iron called for, but requires it to be sufficiently tough to allow the castings to be readily drilled, chipped, or filed.

Cast iron may contain as much as 6 per cent of carbon, partly chemically combined, and partly existing as free carbon. Silicon, phosphorus, manganese, and sulphur are also present in varying small percentages.

Cast iron is a brittle metal and before failure takes place exhibits no yield point and shows small elongation and reduction in area of the test piece. Failure takes place by a sudden clean break in tension (see Fig. 29A), while in compression the test piece bulges out a little and then fails in shear, the shear line being inclined at about 45° (see Fig. 29B).

A brittle casting can be toughened by surrounding it in an annealing furnace with powdered oxide of iron, which at a white heat will gradually absorb carbon from the surface of the cast iron, changing it from a brittle to a malleable material. Small castings can be made malleable throughout.

Wrought Iron. Instead of the direct method used from time immemorial of *reducing* iron oxide by heating with charcoal, wrought iron is now usually produced by the *puddling* process. This consists of heating pig-iron on a suitable tray lined with a basic and oxidizing material by hot air from a separate *reverberatory* furnace. Impurities are squeezed from the spongy mass of iron and slag thus produced by means of the steam-hammer, and the resulting *bloom* rolled into *puddled bars*; these bars are cut into suitable lengths to form *piles*, heated in a furnace to a welding temperature, and then rolled into the required shape. The resulting product is a fibrous and ductile material.

The British Standard Specification No. 51 specifies varying tensile strengths, depending on the grade, shape, and size of the material, and also whether the test is made along or across the grain. It also specifies the minimum

percentage elongation required as a measure of ductility, and also various bending and welding tests.

Wrought iron is a ductile material and can be drawn out to considerable length before failure in tension occurs (see Fig. 29C). In compression, the metal exhibits a marked yield point before the test piece starts rapidly to squash. Finally, failure occurs by the metal becoming plastic and the fibres weakening, causing cracks to appear in the specimen (see Fig. 29D).

Mild Steel : Manufacture. There are several processes for producing mild steel from pig-iron.

In the *Bessemer process*, the impurities in the pig-iron are removed by oxidation, when air is blown through the molten metal in a bottle-shaped *converter*.

If the pig-iron contains phosphorus, the presence of which in the finished product causes cold *shortness* (that is, brittleness when cold), the converter is lined with a *basic* material, such as dolomite (a magnesium and calcium carbonate), which forms with the phosphorus a phosphate slag.

If no phosphorus is to be removed, the lining is *acid*, usually ganister (chiefly composed of silicon oxide), and the slag formed consists of silicates.

In both acid and basic processes, carbon and manganese are completely removed in the waste gases and slag respectively, and the requisite amount is re-introduced by the addition of *spiegeleisen*, a cast iron rich in manganese.

The manganese assists soundness and counteracts *red shortness* (that is, brittleness when hot), due to the presence of sulphur.

In the *open-hearth* process, the furnace is heated by passing through it air and gas fuel separately heated, which unite in the furnace with an intensely hot flame.

The heated products of combustion are passed through *regenerators*, which absorb their heat and afterwards give it out again to the fresh air and gas passing through them on their way to the furnace. As in the Bessemer process, the hearth lining is either acid or basic. Scrap-iron is also mixed with the pig-iron, together with a certain amount of ore.

After all the manganese has been removed in the slag, and when the carbon-content is as required, the oxidation process is stopped and the required amount of manganese introduced by the addition of *ferro manganese* (that is, an alloy of manganese and iron).

In the basic process, however, by which any quantity of phosphorus can be removed, carbon is also eliminated, and both carbon and manganese may have to be added to the steel in the ladle.

Sulphur can be removed by putting calcium chloride and fluoride in the bottom of the hot

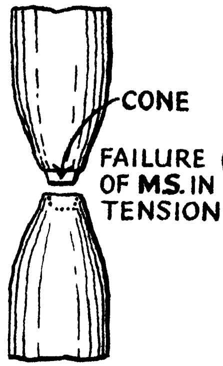


FIG. 29E

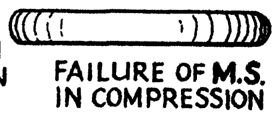


FIG. 29F

metal ladle, and pouring off the slag subsequently produced. It is often, however, removed as manganese sulphide in the basic slag.

The steel is poured into moulds to form *ingots* of a suitable size, which are either directly or after reheating dealt with in the rolling mills.

The subject of rolling, and the various sections of steel available for the use of the structural engineer, will be dealt with later.

Failure of mild steel occurs by the specimen gradually necking at some place on its length and a piece finally shearing across in the form of a cone (see Fig. 29E). In compression the metal exhibits a marked yield point, after which it becomes plastic and can be flattened more or less completely (see Fig. 29F).

Properties of Steel. The British Standard Specification provides for two grades of mild steel for general building construction: (*A*) made by the open-hearth process, and containing not more than ·06 per cent of sulphur or phosphorus; and (*B*) made either by the open-hearth or Bessemer process (acid or basic), with not more than ·08 per cent of phosphorus and ·06 per cent of sulphur. The latter grade is not intended for use in bridges, for plates ½ in. thick and over, and for rivets, nor can Grade *B* steel be used when the higher stresses and lower live loads of B.S.S. 449 are employed.

When a bar of steel is tested to destruction in a tensile testing machine, the length increases

uniformly with a strain proportioned to the stress, up to about 60 per cent of the stress causing fracture. When the strain increases more rapidly than the stress, the *elastic limit* has been reached, and the metal is plastically stretched without returning to its initial length, when the stress is removed. Such increase in length is termed a *permanent set*.

At a slightly higher stress the material stretches very rapidly without an increase in the load. The point at which this stretching occurs is known as the *yield point*, and it is the stress causing this definite flow of material which is usually recorded, and not the elastic limit which only very careful measurement discloses.

Fig. 30 shows graphically a record of such a tensile test in the line *A*.

A similar record of a test on wrought iron is indicated by line *B*, the strains to a larger scale being indicated by the broken lines A_1 and B_1. The line C_1 is the record of a tensile test on a cast-iron specimen, where there is no indication of a yield point.

The stretch at yield point continues till a length is reached, when the load on the bar can be further increased with a further plastic stretching.

With a greater load the specimen stretches locally, with a resulting marked decrease in diameter, and if the load is not removed the bar will break at the narrow neck thus formed. If the load is removed and some time is allowed to lapse before it is re-applied, it will be found that a greater load is required to start a further plastic stretch, the stretching having raised the yield point of the material.

In the figure the stresses are measured on the original section of the specimen.

The actual stresses on the decreased section continually increase.

It is usual to put gauge marks on the bar tested, so as to be able to measure the percentage elongation of the material, this percentage being a measure of the ductility of the steel. As the greater part of the stretch is local, a higher percentage elongation is required for short specimens than for long ones. With material of small area there is not so much metal from which the neck can be drawn, so that a less percentage elongation is expected for small diameters than for large.

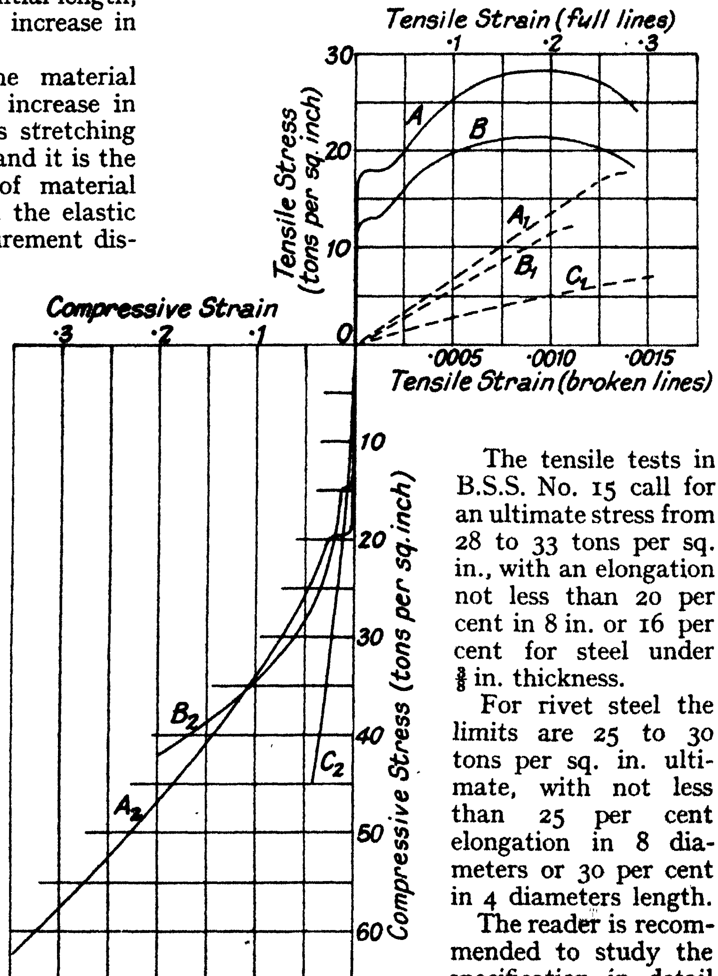


FIG. 30

The tensile tests in B.S.S. No. 15 call for an ultimate stress from 28 to 33 tons per sq. in., with an elongation not less than 20 per cent in 8 in. or 16 per cent for steel under ⅜ in. thickness.

For rivet steel the limits are 25 to 30 tons per sq. in. ultimate, with not less than 25 per cent elongation in 8 diameters or 30 per cent in 4 diameters length.

The reader is recommended to study the specification in detail for the bending and other tests required.

Fig. 30 also shows records of compression tests on steel, wrought-iron, and cast iron in curves A_2, B_2, and C_2 respectively.

As for metals the modulus of elasticity is the same in compression as in tension, and the elastic limit is usually not less in compression than in tension, and as also a tension test is much simpler than a compression test, it is usual to dispense with the latter and rely on the former only for information as to the strength of the material.

B.S.S. 449 specifies the stress limits given in Table IX.

For grillage beams such as those illustrated on page 1144, not less than 3 in. apart and completely encased in a 1 : 6 or richer concrete with a minimum concrete cover of 4 in., B.S.S. 449 allows 50 per cent higher stresses than the above.

Also for filler joist floors calculated as composite beams in the manner discussed on page 1090, B.S.S. 449 allows 9 tons per square inch as the safe maximum tensile stress instead of 8 tons per square inch.

It will be noted that the bearing stress is taken as twice the allowable shear stress, but when a plate is enclosed between two other plates, it is safe to use a 25 per cent higher bearing stress on the enclosed metal, though not permitted by B.S.S. 449.

IMPORTANCE OF DUCTILITY. Rolled steels with a large amount of carbon in their composition have a higher elastic limit and ultimate strength, but the percentage elongation is much less than for mild steel. Such high-carbon steels are not considered suitable for use in building construction.

In a group of rivets connecting two members in tension, imperfections of workmanship may cause an undue share of the total load to be carried by one rivet. If the rivet could not deform plastically the overstress might cause failure, possibly throwing the whole load on to another rivet, and so on till all were broken. In practice the rivet would *give* slightly without fracture, and all the rivets would ultimately get their share of the load.

Similarly, if a member of a structure is subjected to a high local stress through shock, that stress, which in a brittle material might cause a local fracture, will in a ductile material be immediately relieved by a plastic deformation.

FATIGUE. It is well known that repeated applications of a stress which is well below that which would cause failure by a single application, may in time break a bar of metal.

If the stress varies from zero to a maximum, as that maximum is reduced with successive specimens of the same material, a greater number of applications is required to break the specimen. The safe limit of stress is that which will fail to break the specimen, however often applied, and this stress is deduced by plotting the maximum stress against the number of applications to cause failure.

If a reversal of stress occurs the safe value of the maximum is less.

For some modern views on this interesting subject the reader may refer to a paper by Mr. H. J. Gough in *The Structural Engineer* for March, 1927. As far as building construction is concerned, the subject may be considered academic, as the design stresses are well within the safe limits.

SPECIAL STRUCTURAL STEELS. By alloying iron and carbon with certain other elements, such as chromium, manganese, nickel, and silicon, it has been possible to produce stronger steels than the mild steel commonly employed; these steels, in addition to possessing high ultimate strength and yield point, also show satisfactory ductility.

These special steels are naturally more expensive, but their use in special circumstances may result in an ultimate economy. For instance, silicon alloy steel has been successfully used in the U.S.A. for large span bridges.

TIMBER

In building construction, timber is chiefly used by the structural engineer for piles, floors, roofs, and temporary structures, of which the formwork for reinforced concrete is an important class.

Timber is usually classified under two headings: (1) fir timber and (2) hard woods. Of the former, *Pinus silvestris*, known as red or yellow deal, red fir, Baltic fir, Scotch fir or pine, and Northern pine, is the staple structural wood of the building industry, and has the merit of being comparatively cheap, light, durable, and easily worked, and has a less tendency to shrink and warp than most woods. In situations where it is exposed to weather, it is superior to the somewhat cheaper *Picea* (or *Abies*) *excelsa*, known as white deal, spruce fir, or Norway pine, and *Picea alba* and *nigra*, known as spruce, which is imported from North America.

Larix Europoea, or larch, is a very strong durable wood, useful for heavy structural work. It is hard, heavy, and weather-resisting, not easy to work, and shrinks and warps more than *pinus silvestris*. It can be obtained in large sizes free from sapwood—the Canadian and American varieties of larch are known as tamarack.

Pinus Strobus, Canadian yellow pine, known also as Weymouth pine and white pine, is not so strong and tough as red fir, but is sound and free from knots. *Pinus resinosa*, American red pine, resembles closely *pinus silvestris*.

Pinus Palustris (or *Australis*), known in this

TABLE IX

British Standard Specification Stress Limits

	Tons per sq. in.	Proviso
(*a*) *For Parts in Tension*		
On the net section for axial stress or extreme fibre stress of all beams.	8	——
On the net section of rivets for axial stress, in the case of rivets driven at the works where the steel work is fabricated.	5	Rivets to be of the usual snap-headed type, with sound well-formed heads of British Standard proportions, hot driven hydraulically or pneumatically, the parts to be riveted together to be in close contact before the rivets are driven.
On the net section of rivets for axial stress in the case of rivets driven at the site.	4	Ditto.
On the net section of bolts for axial stress.	5	The bolts to be in no case less than $\frac{3}{4}$ in. diameter and of British Standard proportions, and the parts to be bolted together to be in close contact before the bolts are tightened up.
(*b*) *For Compression Flanges of Beams*		
On the gross section for extreme fibre stress of beams embedded in a concrete floor or otherwise laterally secured.	8	Where holes not completely filled by rivets or turned bolts occur in compression flanges, the extreme fibre stress on the net section shall not exceed 8 tons per square inch.
On the gross section for extreme fibre stress of uncased beams where the laterally unsupported length *L* is less than twenty times the width *b* of the compression flange.	8	Ditto.
On the gross section for extreme fibre stress of uncased beams where *L* is greater than twenty times *b*.	$11{\cdot}0 - 0{\cdot}15\,\frac{L}{b}$	Ditto. In no case may the ratio $\frac{L}{b}$ exceed 50.
(*c*) *For Parts in Shear*		
On the gross section of webs.	5	With thin webs and large shearing stresses, provision must be made against buckling.
On shop rivets and tight-fitting turned bolts.	6	
On field rivets.	5	*Note.* The strength of rivets and bolts in double shear may be taken as twice that for single shear.
On black bolts, where permissible.	4	
(*d*) *For Parts in Bearing*		
On shop rivets and tight-fitting turned bolts.	12	
On field rivets.	10	
On black bolts, where permissible.	8	

Note. For beams solidly encased in concrete, the breadth *b* in the formula may be taken as the width of the compression flange of the beam *plus* the least concrete cover beyond the edge of the flange on one side only with a maximum of 4 in.

country as pitch pine, or the long-leaf pine of North America, is often shipped with Cuban pine and loblolly pine, from which it is not easily distinguished. It is very free from knots, but is much heavier than *pinus sylvestris*.

The pitch pine of the States (*Pinus rigida*) is not exported to any great extent.

Pseudotsuga Douglasii, Oregon and British Columbian pine, known also as Douglas fir, is straight-grained and sound, and is valuable for large roof timbers, being obtainable in large dimensions, free from injurious knots.

Of hard-wood timbers there are many varieties of oaks. The English oaks are the strongest and most durable of European timbers. The European oaks are nearly as strong, but the American oaks are much inferior in strength and more easily worked.

Of other hard woods used by the structural engineer, may be mentioned *greenheart* from Demerara, *jarrah* (of the eucalyptus family) from Australia, both of which are strong, heavy, and durable, and valuable for piles; *beech*, a compact wood, comparable to oak in strength, though lighter but not durable if exposed alternately to wet and dry; *elm*, a tough wood, difficult to work and subject to warping, also used for piles; and *teak*, of great strength and durability, whose fire-resisting properties make it very useful for the construction of staircases.

As a structural material, timber of the same species may show considerable strength variations, owing to differences in place and rate of growth, seasoning, the presence of knots, shakes, etc. The method of growth makes the strengths parallel and at right angles to the grain very different.

Good timber is procured only from the heart of a tree, the sap being removed by seasoning. The wood will be uniform, straight and free from the blemishes mentioned below. The wood should smell sweet; a musty or bad smell denotes decay. A chalky appearance is bad.

Timber is subject to various defects, some produced during growth, and some during seasoning, or conversion of the baulk into usuable timber. Shakes are very common defects, and are of various kinds. *Heartshakes* (Fig. 31) are splits in the centre of the tree. It depends upon the position and extent of the shake as to how the timber can be sawn. Thus, in the sketch, four splits occur, so that in *a* and *b* scantlings a fair size would be obtained, while in *c* and *d* the scantlings would be smaller. So long as the shakes are straight, the timber can be used for conversion, but when the shakes twist, it is impossible to obtain timber of any usable length. *Starshakes* occur where several splits radiate from the centre of the tree. *Cup-shakes* are those which occur between two annular rings.

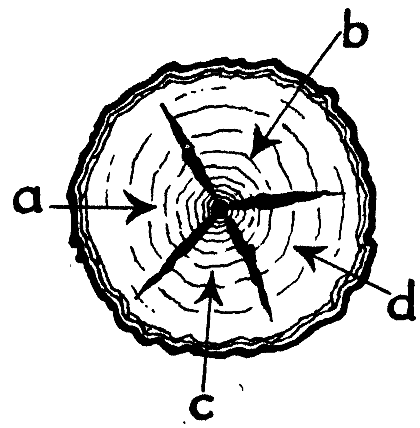


FIG. 31

When timber is sold, the sizes usually stated give the dimensions of the timbers when first sawn. The actual sizes are less, due to shrinkage and planing, the former varying with the timber and the latter reducing the sawn dimension by $\frac{1}{8}$ in. to $\frac{3}{16}$ in. for each working.

Thus, a planed board 11 in. by 1 in. would actually measure less than $10\frac{7}{8}$ in. by $\frac{7}{8}$ in.

Sawn timbers are classified as *whole timbers* (say, 9 in. to 18 in. square); *half timbers*; *planks* (18 in. to 11 in. by 6 in. to 3 in.); *deals* (9 in. by 4 in. to 2 in.); and *battens* (7 in. wide and narrower).

In attempting to arrive at the strength of timber by testing, the results on a small specimen free from knots should be discounted when applied to structural sizes.

In Trautwine's *Engineers' Handbook* the central breaking loads are given of sections 1 in. square and 12 in. long between bearings. The figures given are: for English oak and pitch pine, 550 lb.; for spruce and white pine, 450 lb.; and for yellow pine, 500 lb.

The bending moment for the central load W is $W \times 12/4 = 3W$ inch-lb. On the assumption that the straight line law holds good up to fracture for a flexural stress (f), the ultimate resistance moment would be $\frac{1 \text{ in.} \times 1 \text{ in.}^2}{6} \times f$, therefore $f = 18W$.

Some experimenters express the strength as the *modulus of rupture*. If P is the breaking weight on a cantilever of length l and rectangular section $b \times d$, then $P \cdot l = b \cdot d^2 \times$ modulus of rupture. The modulus of rupture is thus one-sixth of the flange stress if the straight line law assumed in beam analysis held good up to fracture.

In Stoney's *Theory of Stresses* the values of the modulus of rupture obtained by various experimenters for European firs and pines is about 1,400, from which the ultimate calculated flexural stress is about 8,400 lb. per sq. in.

As a guide to the allowable timber stresses for different conditions, the figures in Table X, adopted by the American Railway Engineering Association, are of interest.

The working stresses in Table X are intended for railway bridges and trestles with no increase of live load stresses for impact.

For buildings in which the timber is protected from the weather, and practically free from impact, the working stresses may be increased 50 per cent. In computing the deflection of beams under long continued load, only 50 per cent of E given in the table should be used.

Masonry, Brickwork, Etc.

For description, weights, and crushing strengths of the various *sandstones*, *limestones*, and *granites* available for the structural engineer in this country, the reader is referred to page 1400, etc. The working stresses permitted in these materials are usually very conservative, a

TABLE X

Strengths of Timbers

Kind of Timber		Douglas Fir	Long Leaf Pine	White Pine	Spruce	Norway Pine	Tamarack	White Oak
Stress		Unit Stresses in lb. per sq. in.						
Extreme fibre	Av. ultimate	6,100	6,500	4,400	4,800	4,200	4,600	5,700
	Working .	1,200	1,300	900	1,000	800	900	1,100
E (average)		1,510,000	1,610,000	1,130,000	1,310,000	1,190,000	1,220,000	1,150,000
Shear								
Parallel to grain	Av. ultimate	690	720	400	600	590	670	840
	Working .	170	180	100	150	130	170	210
Longitudinal in beams	Av. ultimate	270	300	180	170	250	260	270
	Working .	110	120	70	70	100	100	110
Compression								
Perpendicular to grain	Elastic limit	630	520	290	370			920
	Working .	310	260	150	180	150	220	450
Parallel to to grain	Av. ultimate	3,600	3,800	3,000	3,200	2,600	3,200	3,500
	Working .	1,200	1,300	1,000	1,100	800	1,000	1,300

In Columns where l = length in inches, d = dimension of least side in inches

$l < 15d$		900	975	750	825	600	755	975
$l > 15d$.	$(1 - l/60d) \times$	1,200	1,300	1,000	1,100	800	1,000	1,300

minimum factor of safety of 10 being common. The crushing strength of granite may range from 1,000 to 3,500 tons per sq. ft., but a common value for the working stress is 40 tons per sq. ft. Table XI gives the safe bearing pressures on stone piers and concrete.

TABLE XI

Rubble (Cement Mortar)	12 tons per square foot
Sandstone (,, ,,)	22 ,, ,, ,,
Granite (,, ,,)	40 ,, ,, ,,
1–6 Mass Concrete	20 ,, ,, ,,
1–10 ,, ,,	10 ,, ,, ,,

Brickwork. The crushing strength of a brick wall, or pier, is usually much less than that of the individual bricks composing it. Bricks vary considerably in strength, and may be roughly classified as *hard* (e.g. Staffordshire Blue brick), *medium* (e.g. Flettons or London stock brick), or *soft*.

B.S.S. 449 lays down conditions for testing bricks and the load at fracture determines the safe stress as given in Table XII.

TABLE XII
SAFE STRESSES IN BRICKWORK

Crushing Strength, 1 lb. per sq in.	Mortar	Maximum Permissible Pressure, Tons per sq ft.
1,500 and upwards	Lime mortar not leaner than 1 . 3	4
1,500 up to 3,000	Cement mortar not leaner than 1 4	8
3,000 ,, 5,000	,, ,, 1 . 4	10
5,000 ,, 7,500	,, ,, 1 3	15
7,500 ,, 10,000	,, ,, 1 : 3	17½
10,000 ,, 15,000	,, ,, 1 : 3	20
The above pressures may be exceeded by an amount up to 20 per cent in all cases where such increased pressure is only of a local nature as at the girder bearings.		
10,000 and upwards	Cement mortar not leaner than 1 : 2	$20 \frac{\text{crushing strength}}{10{,}000}$ but not greater than 40.

Concrete is a mixture of Portland cement, sand, and coarse aggregates. The sand should be clean and sharp. The aggregate consists of broken stone, pebbles, crushed rock, and some kinds of furnace slag are suitable.

Ordinary coke clinkers or ashes are not suitable for reinforced concrete construction which has to carry loads. The quantities used are called the mix and are measured by volume, not weight. The most common mix is 1 : 2 : 4, which means 1 part of cement, 2 parts of sand, 4 parts of broken stone or pebbles. The reader should refer to the section on Concrete: Plain and Reinforced, for further information on this important material.

Asbestos is now very largely used in various forms. Corrugated asbestos-cement sheets are used for roof coverings (*see* Roof Coverings) and sides of buildings; asbestos-cement tiles are quite common, durable, and easy to erect.

One of the points to keep in mind when using asbestos fibre sheets is that they get hard and brittle if kept in store for a year or two. They then require very careful handling and are difficult to cut.

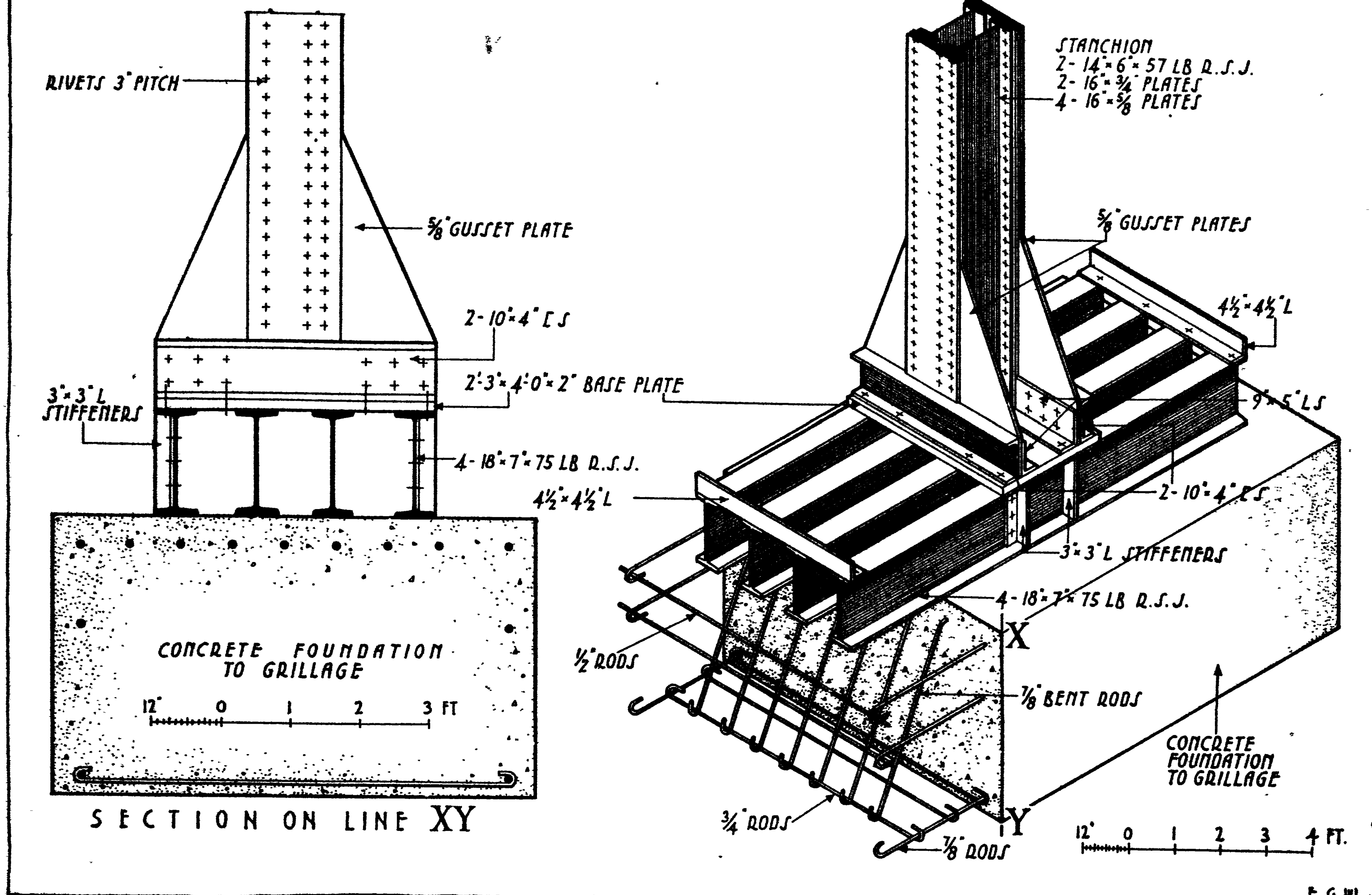
It is quite easy to damage even new sheets when unloading from load trucks, if this is carelessly done.

Fibre-glass. One of the insulating materials that has come to the forefront in recent years is fibre-glass or glass-wool. It is made by blowing jets of steam through streams of molten glass. This forms a fluffy mixture something like cotton-wool. Bitumen is mixed with this fluff and the product looks like a blanket about 1 in. thick. The fibre-glass can be made in rolls, 30 to 40 ft. long. The material can be easily cut with a sharp knife and has very good insulating properties. *Slag wool* is produced by blowing jets of steam through furnace slag. This material has good insulating properties and has been used on some recent housing construction. It has long been used on board ship where insulation of heat and cold is required.

Aluminium. Because of its lightness aluminium is being increasingly employed in various kinds of engineering work, e.g. overhead travelling cranes, wagons. Special shaped sections have been successfully used.

The structural engineer is all the time using more materials than his forefather had available. Perspex, fibre-boards, gyproc, plastics, are all well known. Wood-wool and cement are made into slabs for housing construction.

GRILLAGE FOUNDATION



Chapter VI—FOUNDATIONS

Supporting Power of Soils. The consistency of " the upper stratum of the earth's crust " varies from that of a liquid, whose supporting power is equal only to the weight of the volume of liquid displaced, to that of rock, such as granite, which will safely carry a load of many tons per square foot.

Between these two extremes there are many varying conditions.

For the first extreme, it is necessary to carry the weight of a building to a more solid substratum by means of *caissons* or *piles.*

Caissons. These are large boxes of timber, iron, or concrete, usually constructed with sharp edges at the bottom to cut into the soil. They sink under their own weight and applied loads, as the soil is removed from under them and carried up through them. When sunk in water the soil is sometimes removed by dredging, but sometimes it is necessary to keep the water out of the working chamber at the bottom by means of air pressure. This means that the sides and top of the caisson must be airtight, and air-locks have to be provided through which the workmen and excavated material have to pass. When the required depth is reached, the caissons are partially or wholly filled with concrete, and the building constructed on top of them.

A type of hollow (concrete) cylinder footing has been successfully used in bridge foundations and for building foundations in bad ground, where a good bearing surface was not found at a reasonable depth below ground level. Its supporting power depends largely on skin friction (*see* Fig. 32).

Piles. These may be posts of timber, steel, or reinforced concrete.

The chief timbers used for foundation piles are Jarrah, Greenheart, Beech, Elm, Pitch Pine, Oregon Pine. For marine work of an important nature Jarrah and Greenheart are the best of all the timbers, but they are expensive, especially if required in long sticks of heavy section. There is also difficulty in obtaining them.

Pitch Pine and Oregon Pine have been successfully used and stand up to conditions very well. Oregon Pine should be protected where it is used in water-logged ground or in marine work by forcing at least 12 lb. of creosote into every cubic foot of timber.

One of the reasons reinforced concrete piles are displacing the timber pile is that they offer resistance to the ravages of teredo. Timber piles should go on to the job longer than the

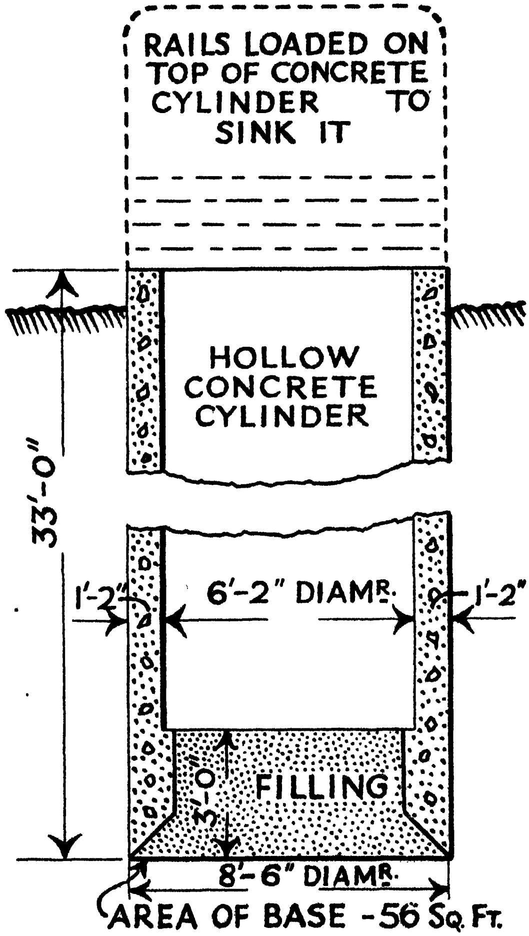


FIG. 32

finished length to allow cutting off the driving head. The head is trimmed down to take a heavy ring of wrought iron. This prevents spreading under the action of the drop hammer.

Both timber and reinforced concrete piles are driven by either a drop hammer or a steam hammer. When driving reinforced concrete piles, it is necessary to put in some sort of a buffer or

cushion between the hammer and the pile; generally a steel helmet is used. This helmet has a disc in the centre of its length and the helmet is lowered over the concrete pile. Generally, there is some sacking between the top of the pile and the underside of the disc. On the top half of the disc there is a timber dolly and this dolly receives the direct blow of the hammer.

Unwrought timber piles are usually driven with blunt ends, and if driven through water the thicker end is sometimes put downwards to give greater resistance from the soil, to prevent them floating up during driving operations.

If a timber pile is pointed, it is usual to fix at the end a pointed shoe of wrought iron or cast iron, similar to those used for reinforced concrete piles.

To facilitate driving, reinforced concrete piles are sometimes cast with a central pipe, through which water can be forced to emerge from the sides and end of the pile.

In the *Raymond* pile, illustrated in Figs. 33, 34, and 35, which illustrations have been kindly lent by the licensees, Messrs. J. & W. Stewart, a thin metal shell, with a removable core, is driven into the ground and filled with concrete after the core is withdrawn. It is claimed that the taper of the pile gives it a greater carrying power.

In *Vibro* concrete piles a thicker metal shell is driven, and as concrete is poured down the shaft the shell is withdrawn gradually with a vibratory motion, which compacts the concrete in the vacated space. Fig. 36, kindly lent by The British Steel Piling Co., Ltd., who are the patentees of this pile, shows an enlarged view of the shoe which remains in the ground.

In *Pedestal* piles of concrete cast in situ a cavity is formed at the bottom of the shaft, so that the finished pile stands on a bulb of concrete.

In marine works, metal *screw piles* are sometimes advisable; these piles have a wrought-iron shaft fixed to a base of cast iron in the form of a screw, which is driven into sand or clay by turning about its axis.

Supporting Power of Piles. The value as a weight carrier of a post driven into the ground is largely due to the friction of the soil on the sides of the post, though the bearing pressure at the tip contributes its share.

Professor Patton, in his *Practical Treatise on Foundations*, gives the value of this skin friction as 100 lb. per sq. ft. in semi-fluid soils, 200 lb. per sq. ft. in compact silt and clay, from 300 lb. to 500 lb. per sq. ft. in gritty earths, and 400 lb. to 600 lb. per sq. ft. in compact sand and gravel.

Many formulae have been devised to express the carrying power of a pile in pounds, and for one set of conditions there are as many values as there are formulae.

A formula taking many factors into account is that due to Mr. A. Hiley (see e.g. *The Structural Engineer* for July and Aug., 1930). It is

$$R = \frac{\eta \, . \, W \, . \, h}{s + \frac{c}{2}} + W + P \qquad (41)$$

where R = ultimate *resistance* of the ground to further penetration by the pile (in tons).

$L = R/F$ = safe load on pile.

F = factor of safety against settlement generally taken as 3 to 4.

c = temporary elastic *compression* (in inches) of the pile and cap, caused by the transmission of pressure corresponding to R.

η = *efficiency* of the *blow*, which depends upon the nature of the materials receiving impact and upon the ratio P/W.

h = *height* of free fall of the ram (in inches). The actual striking velocity depends upon the height of free fall and h is taken as 92 per cent of stroke for single acting steam hammers, and 80 per cent for drop hammer actuated by friction winch.

s = *set*, or penetration of pile per blow, expressed in inches.

P = *weight* of *pile* (in tons) including all component parts, such as the shoe, helmet and driving cap or anvil, which are set in motion by the hammer blow.

W = *weight* of the *ram* which constitutes the kinetic member of the hammer (in tons).

For the efficiency of the blow the values given in Table XIII may be used, depending on the ratio of P to W and the type of hammer and pile.

The values of C given in Table XIV are taken from a chapter on Mr. Hiley's formula in *Modern Steelwork* (1927).

THE RAYMOND PILE

Fig. 33

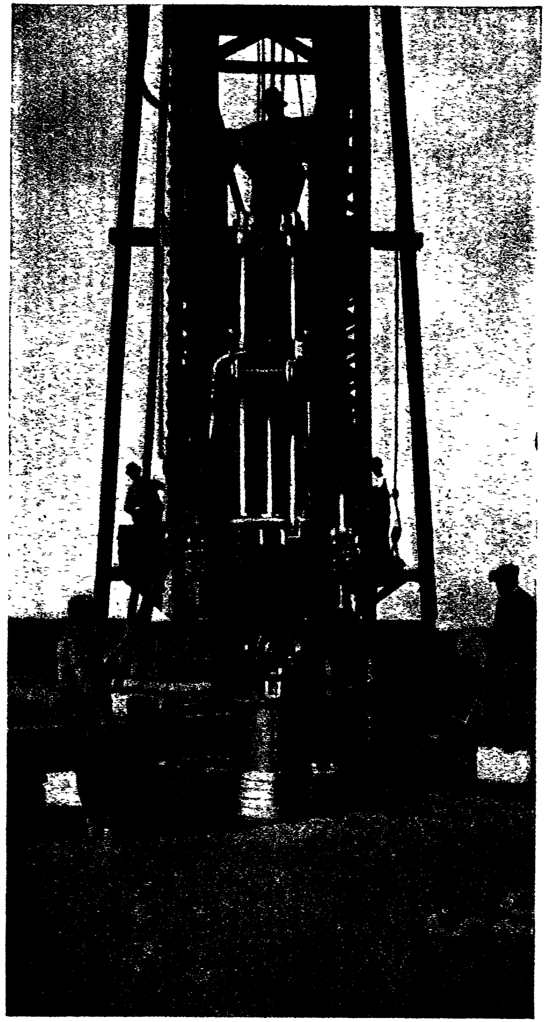
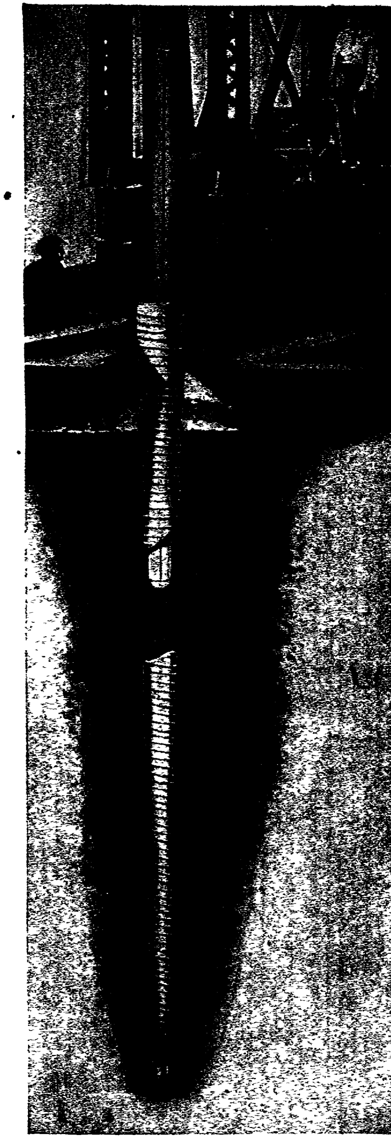


Fig. 34



(J. & W. Stewart)

Fig. 35

TABLE XIII

VALUES OF EFFICIENCY BLOW η

$\overline{W}$	Double-acting Hammer		Single-acting or Drop Hammer	
	R.C. Piles	Timber Piles	R.C. Piles with Helmet and Dolly and Timber Piles	Timber and R.C. Piles with Cap in Deteriorated Condition
½	·75	·72	·69	·67
1	·63	·58	·53	·50
1½	·53	·50	·44	·40
2	·50	·44	·37	·33
2½	·45	·40	·33	·28
3	·42	·36	·30	·25
4	·36	·31	·25	·20
5	·31	·27	·21	·16
6	·27	·24	·19	·14

TABLE XIV

TOTAL TEMPORARY COMPRESSION "c" IN INCHES

Ultimate resistance, R ÷ pile area (pounds per sq. in.)	Timber Piles				R.C. Piles with Helmet and Dolly			
	500	1,000	1,500	2,000	500	1,000	1,500	2,000
Length of pile—								
20 ft. . .	·11	·19	·30	·41	·14	·25	·39	·52
30 ft. . .	·15	·26	·41	·56	·17	·30	·47	·64
40 ft. . .	·19	·33	·52	·71	·20	·35	·55	·75
50 ft. . .	·23	·40	·63	·86	·23	·40	·63	·86
60 ft. . .	·27	·47	·74	1·00	·26	·45	·71	·97

EXAMPLE. A 14 in. × 14 in. timber pile 40 ft. long and weighing 1 ton is required to carry a load of 35 tons. What is the set that should be specified if a drop hammer of 2 tons falling 40 in. is used?

SOLUTION. h = 80 per cent of 40 = 32 in.

With a factor of safety of 3 the ultimate resistance R = 105 tons.

The stress in the pile $= \frac{105 \times 2240}{196} =$ 1200 lb. per sq. in.

$$\frac{P}{W} = \frac{1}{2}\,;\ n = \cdot 69$$

$$c = \cdot 33 + \tfrac{2}{5}(\cdot 52 - \cdot 33) = \cdot 406$$

$$105 - 2 - 1 = \frac{\cdot 69 \times 2 \times 32}{s + \cdot 203}$$

$$S = \frac{\cdot 69 \times 2 \times 32}{102} - \cdot 203 = \cdot 432 - \cdot 203 = \cdot 23 \text{ in.},$$

say 1 in. in last 5 blows.

The problem of pile driving is of such a nature that no formula can be universally applicable. A pile can be driven with little difficulty into swampy ground, and its bearing value calculated by any of the formulae commonly employed is very small; but if an attempt is made later to drive it farther, it will be found that its resistance to further driving is considerable, and many buildings have been satisfactorily constructed on such piles.

It is sometimes specified that the piles must be driven till so many blows of a hammer of definite weight and fall produce less than a certain penetration per blow (say, 30 blows of a 2,000 lb. hammer falling 20 ft. shall not produce more than ½ in. penetration per blow). There is an element of danger in such a requirement, as it is impracticable to measure the penetration of each blow, and the first of a series may produce no penetration, with the result that the energy of succeeding blows will be expended in damaging the pile. It is generally wise to use a relatively heavy hammer with a small drop in preference to a light hammer with a long drop. A lot of energy can be wasted in bouncing.

(*The British Steel Piling Co., Ltd.*)

FIG. 36. PILE BASE

A single pile is sometimes placed under a column, but more often piles are driven in groups under concentrated loads, their tops, cut off at one level, being joined together by a slab forming the *pile cap*.

Isolated Column Footings. A sufficiently hard stratum to carry safely the weight of a building is often found quite near the surface. To discover what pressure may safely be put on it, loads on a definite area may be applied and the settlements measured. Experience will often enable an engineer to gauge the safe pressure by an examination of the soil and information as to the substrata, which trial bore holes will give. If the foundations are on a soil such as clay or gravel, the engineer's object will be to keep the ultimate settlements under load small and as uniform as possible. To achieve this, the size of the loaded areas must be sufficiently large and proportional to the loads coming on them, so as to make the stress on the subsoil uniform.

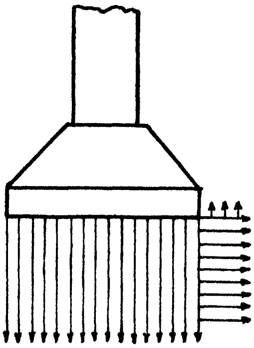


FIG. 37

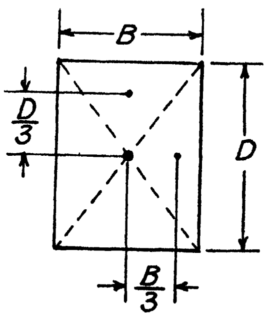


FIG. 38

The design loads on the floors of many buildings will rarely be realized, and sometimes the size of the footings is made proportional to the dead load only, the stress to be taken being that caused by the dead load in the footing on which the ratio of live to dead load is a maximum and whose size is determined by the safe stress for total load. In some cases a percentage of the live load, which the engineer's judgment must determine, is added to the dead load.

The permissible ground pressures in tons per square foot given in B.S.S. 449 are shown in Table XV.

These pressures may be exceeded by an amount equal to the weight of the material in which a foundation is bedded and which is displaced by the foundation itself, measured downward from the final finished lowest adjoining earth level, or the upper level of any solid raft directly on the earth.

TABLE XV

GROUND LOADS

	Permissible Load on Ground (tons per sq. ft.)
Alluvial soil, made ground, very wet sand	½
Soft clay, wet or loose sand . .	1
Ordinary fairly dry clay, fine sand, loam	2
Firm dry clay	3
Compact coarse sand, confined sand, London blue clay, and similar hard compact, coarse gravel .	4
Hard solid chalk	6
Shale and soft rock . . .	10
Hard rock	40

Depth of Footings. If a vertical pressure of p lb. per sq. ft. is applied to a horizontal surface by the base of a column such as that illustrated in Fig. 37, according to Rankine's theory of earth pressure, there will be a horizontal pressure in the soil equalling

$$p \cdot \frac{(1 - \sin\phi)}{(1 + \sin\phi)},$$

where ϕ is the angle of repose or natural slope of the soil. This expression may also be written

$$p \cdot \tan^2 (45^\circ - \phi/2),$$

a form more useful for slide rule calculation.

From this horizontal pressure there will result an upward pressure equalling $p \cdot \tan^4 (45^\circ - \phi/2)$, and unless the soil by the side of the column base is sufficiently loaded, it will be pushed up as the base sinks down. If, for example, the natural slope is 35°, $\tan (45^\circ - 17\tfrac{1}{2}^\circ) = \cdot 5206$, $\tan^2 \phi = \cdot 27$. If the downward base pressure is 2 tons = 4,480 lb. per sq. ft., the corresponding horizontal pressure is 1,210 lb. per sq. ft., and the resulting upward pressure is 327 lb. per sq. ft.

If the soil weighs 100 lb. per cub. ft., it would thus require a depth of 3 ft. 3 in. to ensure that the soil surrounding the base will not rise up as the base sinks.

It will be found, however, that a smaller cover than Rankine's theory indicates will achieve this end. This is due partly to the fact that most soils possess cohesion, which enables them to stand vertically when first cut into, and partly due to a different pressure distribution from

that assumed by Rankine. This will be discussed later.

Footings, however, should be placed a sufficient distance below the surface to be beyond the effect of the weather. This distance will vary with both soil and climate. If clay is so situated that in the summer it will dry, shrink, and crack for a distance of 6 ft. below the surface, the footings must be placed deeper than 6 ft. If frost does not penetrate more than 4 ft. into gravel, such a depth would be suitable for footings therein.

Design of Isolated Footings. For a footing of concrete, such as that shown in Fig. 37, a common rule for determining the suitable thickness is to divide the total load on the base area outside the column by the product of the column periphery and the safe "punching shear" usually taken as twice the allowable shear stress in concrete not reinforced for shear.

For concrete giving a crushing strength on a cube of 2,400 lb. per sq. in. in four months, 120 lb. per sq. in. is a suitable value for this punching shear.

Thus if $4d$ is the perimeter of a square column in inches, the load on the base area outside the column should not exceed $480 \cdot d \cdot t$ lb., where t is the thickness of the base in inches.

When a point load of P tons from a column comes in the centre of a rectangular slab of area $B \times D$ sq. ft. (see Fig. 38), it is common practice to assume that the bending moment about the axis parallel to D is $\frac{P \cdot B}{12}$ ft.-tons, and about that parallel to B is $\frac{P \cdot D}{12}$ ft.-tons.

These values are deduced from considering that the upward load is divided by the diagonals into four triangular portions of equal area, the centre of gravity of those with D as base being $B/3$ from the centre, and those with B as base being $D/3$ from the centre. The load on each being $W/4$, the bending moment is the product of load and lever arm.

For a square base where $B = D$, the bending moment in each direction is $\frac{P \cdot B}{12}$ ft.-tons, $= P \cdot B$ in.-tons $= P$ in.-tons, per foot width of base.

If the dimensions of the column are $b \times d$, the downward load may be considered as similarly divided into four triangles, and in the expressions for bending moments $(D - d)$ may be substituted for D, and $B - b$ for B.

For rectangular steel base plates, however, with an assumed uniform bearing pressure, B.S.S. 449 specifies the minimum thickness as the greater of the two values

$$\sqrt{\frac{3W \cdot (B-b)}{4f \cdot D}} \text{ or } \sqrt{\frac{3W \cdot (D-d)}{4 \cdot f \cdot B}}$$

Where W is the axial load in tons,
d is the dimension of the steel pillar in one direction,
D is the dimension of the base parallel to d,
b is the dimension of the steel pillar at right angles to d,
B is the dimension of the base parallel to b,
f is the allowable stress in tons per square inch taken at 9 tons per square inch.

This is equivalent to taking the bending moment across the section parallel to b as $\frac{W \cdot (D-d)}{8}$, which must equal the product of the section modulus $\frac{B \cdot t^2}{6}$ and the stress f, and the bending moment across the section parallel to d as $\frac{W \cdot (B-b)}{8}$, which must equal $\frac{D \cdot t^2}{6} \times f$.

For caps and bases of round steel pillars, with a reduced diameter d, round which the cap or base is shrunk or screwed, the maximum bending moment is taken as $\frac{WD}{8}$, where D is the longer side of cap or base. This must equal $(B) - d \times \frac{t^2}{6} \times f$ and $t = \sqrt{\frac{3 \cdot W \cdot D}{4 \cdot f \cdot (B-b)}}$, the value given in B.S.S. 449.

In reinforced concrete the top of the base slab may be shelved as indicated in Fig. 37, or the footing may be stepped in a manner similar to that for a brick pier.

Grillage Foundations. For a steel stanchion, the requisite spread of the footing is often obtained by placing the base of the stanchion in the centre of a group of joists, which in turn rest on other joists; sometimes a third tier is necessary to obtain the requisite area to distribute the load.

In grillages the upward load is assumed to be equally divided between all the joists in each tier, and if W tons is the share of the load on

one joist of length L ft. carrying the load on a breadth B, the maximum bending moment in the joist is usually taken as $W \cdot (L - B)/8$ ft.-tons, the bending moment and shear diagrams being as in Fig. 39.

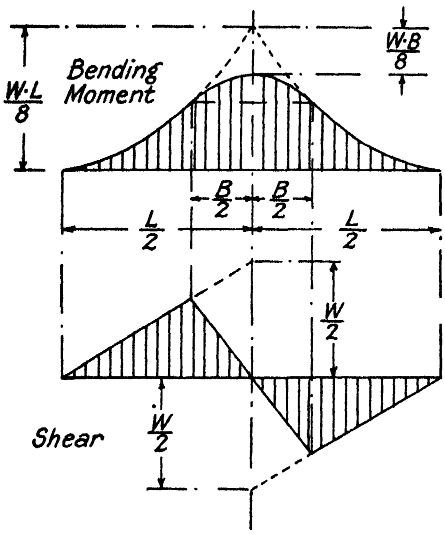


FIG. 39

The dotted lines going to the centre line indicate the diagrams for the downward load concentrated at a point at the centre, the

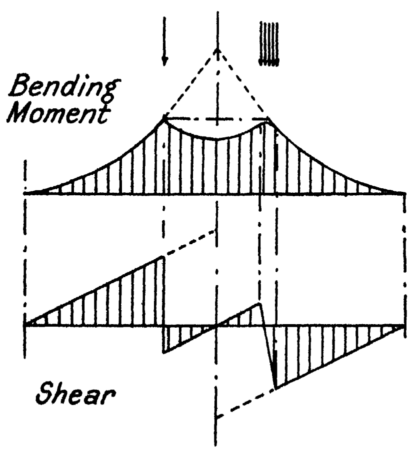


FIG. 40

distribution of the downward load over a breadth B reducing both shear and bending moment as shown. For Fig. 39 to represent the actual conditions, the material of breadth B, bringing the load on the joist, must deform to the same extent as the joist below. For a stiff stanchion base on the top tier of beams, this can hardly be expected, and the load will probably be concentrated under the flanges,

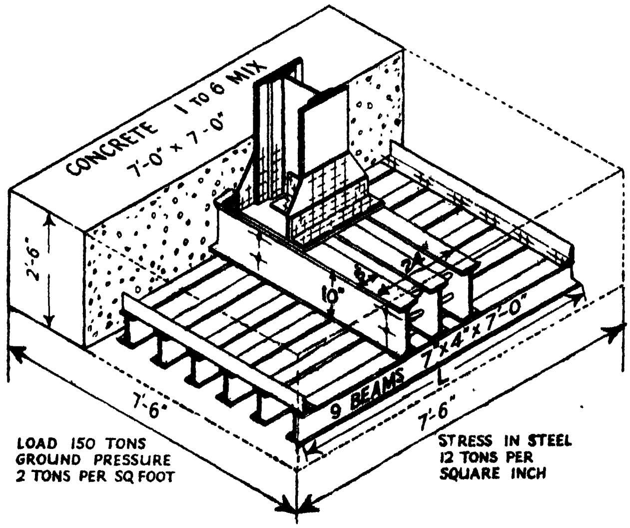


FIG. 41

in which case the shear and bending moment diagrams will be as in Fig. 40; on the left is shown the diagram for concentration at a point, and on the right the modification allowing for a width of bearing. It is usual, however, to adopt the larger bending moment of Fig. 39 from which to deduce a suitable joist. Although it is common practice to use the larger bending moment shown in Fig. 39, there is no doubt that this gives "something in hand," and if the designer finds that he can get beams from rolling mills, or from his own firm's stock, quicker by using a somewhat smaller section than is actually required by using this maximum bending moment, he need have no worries if he puts in a grillage which will satisfy the bending and shear shown in Fig. 40. Again, if the concrete block is kept the same width and length through the whole of the depth, there is sound sense in using a safe stress of 10 or 12 tons per square inch for bending stresses. Stiffeners are riveted to the webs of the top tier of joists when the stanchion load is very heavy.

Each tier of joists must be tied together. In Fig. 41 bolts with gas pipe separators will be

observed in the top tier, and an angle bolted to the top flanges for the lower tier.

EXAMPLE.

A column (Fig. 41) carries a load of 130 tons. The ground is safe to carry 3 tons on each square foot. What would be suitable sizes for a two-tier grillage?

Weight of concrete block and grillage beams will have to added to the load on the column. Guess 20 tons for grillage beams and concrete, then total load $130 + 20 = 150$ tons.

$$\text{Area of concrete beaming} = \frac{150}{3} = 50 \text{ sq. ft.}$$

Use footing 7 ft. 6 in. square and make lower set of beams about 7 ft. square. The footing will be 6 in, below the bottom flange of lower set of steel beams. and 4 in. or 6 in. above the top flange of upper set of beams. Total depth of block probably about 30 in. (From this rough size of concrete it can be found that the guess of 20 tons for the weight of the footing is sufficiently near.)

The foundation block will be made of the same horizontal section throughout. (In many cases the concrete is reduced at the top set of beams.) By keeping section constant the stress in the steel beams can be 12 tons per sq. in.

The beams will be designed on the assumption that bending moment takes the form shown in Fig. 39. Let width of top tier be 2 ft. and call this l. The base plate is 2 ft. square, and it is reasonable to take the well-stiffened base as distributing the load over a length of 2 ft.

For the top tier of beams we have a length L of, say, 7 ft. On the underside an upward pressure uniformally distributed which amounts in total to the load on the column 130 tons. If the load from the column acted at a point in the centre of the beams the bending moment would be

$$\frac{W}{2} \times \frac{L}{4} = \frac{W \times L}{8}$$

The column base acts as the support against the upward pressure and is not at a point, but spread over a length of 2 ft. 6 in. For this reason the curve in the centre 2 ft. of the bending moment curve takes the form shown in Fig. 39, and does not go to a point. The bending moment will therefore be less than $WL/8$. If we call the length of the base plate B, the formula for the maximum bending moment at the centre line of the top tier of beam is

$$\frac{W}{8}\ (L - B)$$

In this case W is 130 tons, L is 7 ft., B is 2 ft.

$$BM = \frac{W}{8}\ (7 - 2) \text{ ft.-tons}$$

$$BM = \frac{W}{8}\ (84 - 24) \text{ in.-tons}$$

$$BM = \frac{130}{8} \times \frac{60}{1} = 975 \text{ in.-tons}$$

Allowing a safe stress of 12 tons per sq. in. in the steel we get $f = 12$.

$$BM = \text{Modulus} \times f$$

$$\text{from which} \quad \frac{BM}{f} = \text{Modulus}$$

$$\frac{975}{12} = 81 \text{ in.}^3 \text{ units}$$

There are three beams, so that each one should have a modulus of 81/3, say, 27 units.

Reference to tables show that 10×5 beam has a modulus of 29 which will do nicely.

Bottom Set of Beams. Here we will use 9 beams; the length of each beam is 7 ft. The top tier has an overall width of 2 ft. B in this case is l.

$$\text{Bending moment} = \frac{W}{8}\ (L - l)$$

$$= \frac{W}{8}\ (7 - 2) \text{ ft.-tons}$$

$$BM = \frac{W}{8}\ (84 - 24)$$

$$= \frac{130}{8} \times \frac{60}{1} = 975 \text{ in -tons}$$

Modulus for beams

$$\frac{BM}{f} = Z$$

$$\frac{975}{12} = 81 \text{ in.}$$

with nine beams modulus for each one will be

$$\frac{81}{9} = 9 \text{ in.}^3 \text{ units}$$

Reference to tables will show that a rolled steel-joist 7 in. by 4 in. has a section modulus of 11·2 and this will do nicely. The complete design is shown in the drawing.

A grillage foundation is levelled on wedges on a bed of concrete, and after the stanchion base is bolted down and adjusted to the exact position required, the space between the concrete and the grillage is filled with cement grout, and the whole of the grillage is encased in concrete.

Combined Footing. If a column is close to the building line of adjoining property under a different ownership, it is often impossible to construct a base central with the column.

It is usual in such cases to carry the column at the end of a beam which rests on a foundation within the building. The other end of the beam must be prevented from rising by means of an anchor load, usually supplied by the dead load on another column.

Fig. 42 shows the combined footing and cantilever beam for two stanchions of the Oxford University Press. Drawing kindly lent by Whitaker, Hall, and Owens, Consulting Engineers.

If W is the stanchion load, P the anchor load, and w the weight per foot run of the cantilever beam, the value of P can be found by taking

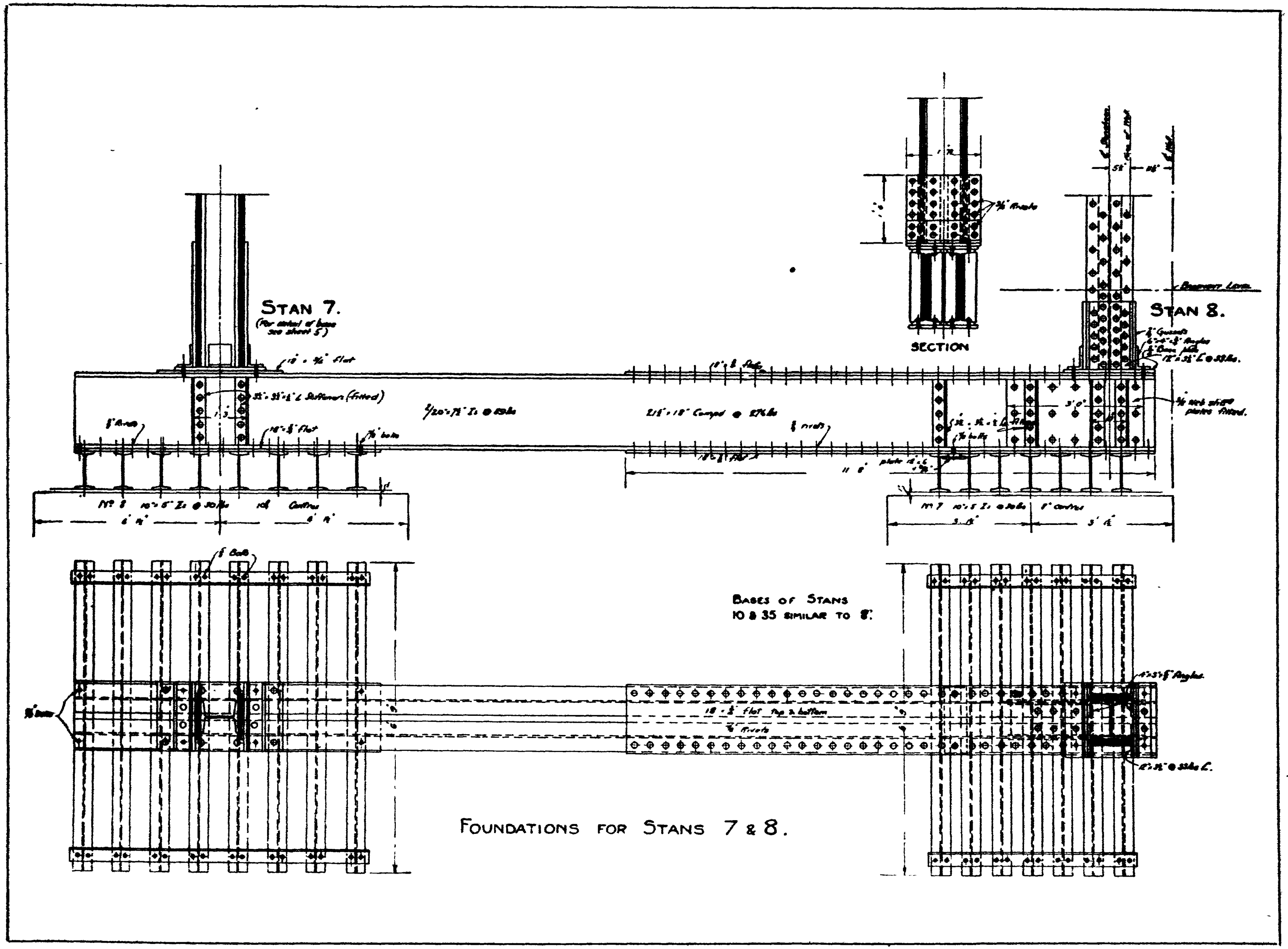


FIG. 42. BASES OF STANCHIONS

moments about the centre of the upward reaction of the foundation. In the case of Fig. 43, the equation would be

$$P \cdot c + w \cdot c^2/_2 = W \cdot a + w \cdot (a + b)^2/_2$$

The total load on the foundation will be

$$P + w\,(a + b + c) + W$$

The maximum bending moment will occur

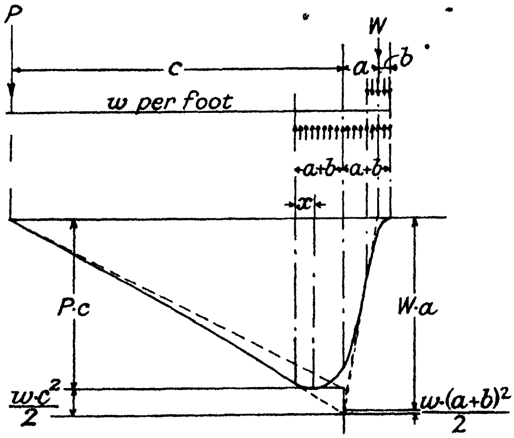


FIG. 43

where the shear is zero. This will be at a distance x from the edge of the foundation, such that

$$\frac{x}{2a + 2b} \times \text{total load on foundation}$$
$$= P + w \cdot (c - a - b + x)$$

The complete bending moment diagram is shown in Fig. 43. It will be noted in Fig. 42 that the web of the cantilever beam has had to be stiffened because of the heavy shear which the steep slope of the bending moment diagram indicates.

Raft Foundations. When the bearing power of the soil is so low that the required size of the isolated footings is so large that they nearly touch, it is common to join them and make a raft foundation.

This may consist of a thick slab or a system of beams and slabs. As the total weight of the building has to be distributed over the whole area of the raft as uniformly as possible, a raft foundation is always more expensive than isolated footings.

Soil Pressure Distribution. It is known that the pressure in soil is not uniformly distributed a short distance under a loaded area, but decreases in intensity with the distance from the centre as indicated in Fig. 44, in the lower part of which curves are drawn for constant depths below the surface, to indicate the percentage of

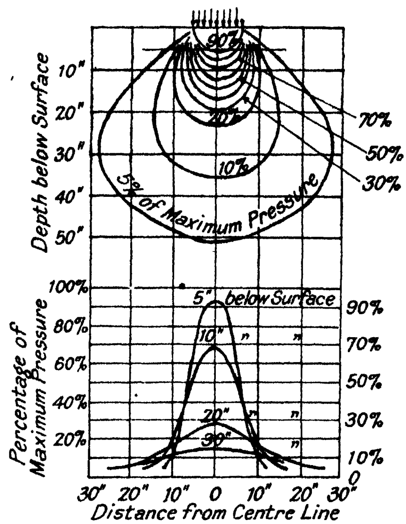


FIG. 44

the maximum pressure occurring immediately below the load, at varying distances from the centre line.

If the results are plotted as shown in the upper portion of the figure, where curves are drawn for constant percentages of the maximum pressure, the so-called *bulb of pressure* is obtained, which clearly shows how the load applied on a small area at the surface spreads over an area which increases with the depth. The greater the depth the more uniform is the load distribution.

The shape of the two sets of curves is similar for sand, loam, and clay.[1]

[1] For blue clay, however, which has a considerable tensile strength, experiments reported by Dr. Faber in *The Structural Engineer* for March, 1933, indicate that the pressures over the edges of a loaded area are greater than at the centre.

Chapter VII—BEAMS AND GIRDERS

WHEN discussing tests on cast iron, it was mentioned that the flexural stress calculated from the breaking load on a rectangular beam does not agree with the breaking stress in direct tension.

This can be accounted for, if the distribution of stress is as shown in Fig. 45, where AB

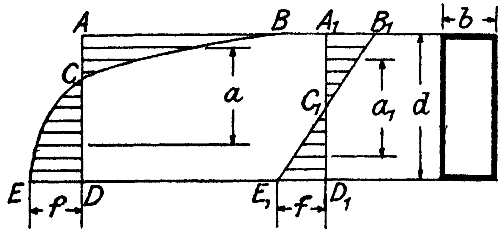


FIG. 45

represents the compressive stress at fracture and DE the tensile stress (f). The area of the curved triangle ABC, multiplied by the breadth b of the section, represents the total compression. The area CDE multiplied by b represents the total tension.

For wrought iron and steel the neutral axis is less eccentric, and the compression area of the stress distribution diagram probably resembles the tension area of Fig. 45.

Structural Shapes. Heated ingots of steel are reduced to shapes and sizes suitable for structural work by being squeezed between pairs of grooved rolls in a *blooming*, or *cogging*, mill. The final section is obtained in a *finishing* mill, the rolls for which are plain cylinders for the production of plates and sheets and grooved cylinders for the production of other sections. Fig. 46[1] shows the type of finishing rolls for angles and joists. As the speed of any part of the roll will vary directly with its distance from the axis of rotation, it is obvious that there must be a sliding motion between part of the rolled section and the roll for all sections except plane plates. This puts a limit to the size of the portion formed by a groove in the roll, which must obviously be tapered. The edges of wide plates produced in an ordinary mill must be subsequently cut square, but in a *universal* mill wide flats are rolled on all four sides to pre-determined width and thickness, the edges being rolled square with the sides by a pair of rolls with vertical axes.

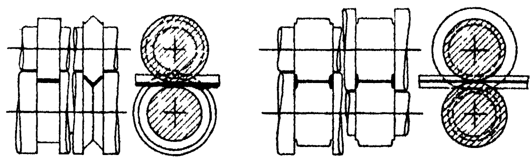


FIG 46

Vertical and horizontal rolls are used in a "Gray" mill for producing broad-flange beams, as indicated in Fig. 47. The horizontal rolls shown in the top of the figure bear on the edges of the flanges and determine the flange width of the beam ; those in the bottom determine the size of the web, while the vertical rolls determine the flange thickness. It will be noted that the flanges of broad-flange beams can be rolled with parallel sides, which is an obvious advantage for bolted connections, as the necessity for tapered washers is avoided.

Particulars of structural steel sections are given in handbooks issued by various manufacturers. Messrs. R. A. Skelton's Handbook No. 19 gives a comprehensive survey of all obtainable sections.

The British Standards Institution issued a revised list of sections for structural purposes in 1924 (No. 6), which was partially superseded by the list of channels and beams issued in 1932 (No. 4). In specifying a standard joist section, the overall dimensions parallel to the web and flanges, respectively, together with the weight per foot run are sufficient to define it. In the new standards there are ***beam sections*** varying from 3 in. × 1½ in. × 4 lb. a ft. to 24 in. × 7½ in. × 95 lb. a ft., and ***stanchion sections*** varying from 4 in. × 3 in. × 10 lb. a ft. to 18 in. × 8 in. × 80 lb. a ft.

The flange taper is 14·05 per cent.

Broad flange beams are obtainable in metric sizes approximating to 4 in. × 4 in. × 13·2 lb. a ft. to 40 in. × 12 in. × 234 lb. a ft.

[1] **The drawings for these blocks have been kindly lent by Messrs. R. A. Skelton & Co., whose latest handbooks give much useful information on structural steel, both technical and commercial.**

For *rolled steel channels* the 1932 standard sections are fewer than those published in 1904, and range from 3 in. × $1\frac{1}{2}$ in. × 4·6 lb. a ft. to 17 in. × 4 in. × 44·3 lb. a ft. The taper of the flange is 3·49 per cent in the old series and 8·75 per cent in the new.

Channel sections are rolled as small as $\frac{3}{4}$ in. × $\frac{3}{8}$ in. There are many Continental and American standard sections of joists and channels. In the American standards, sections of one depth are rolled to several different weights.

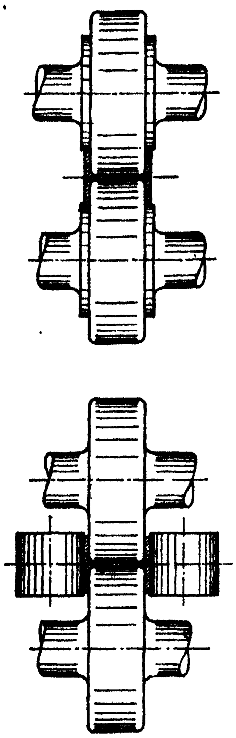


FIG. 47

Angle sections are rolled with the legs equal or unequal, and are specified by the overall dimensions of the legs and the thickness of metal. The British standard equal-sided angles range from $\frac{3}{4}$ in. × $\frac{3}{4}$ in. × $\frac{1}{8}$ in. to 9 in. × 9 in. × $\frac{3}{4}$ in., though the last section is not yet rolled. The range for unequal-sided standard angles is from 2 in. × $1\frac{1}{2}$ in. to 10 in. × 4 in. They are obtainable in thicknesses varying by $\frac{1}{16}$ in.

The dimensions of *tee sections* are usually given in the following order: (1) width of the table; (2) overall depth of the stem; (3) average thickness of the metal. The British standard sizes range from 1 in. × 1 in. × $\frac{1}{8}$ in. to 6 in. × 6 in. × $\frac{5}{8}$ in. and 7 in. × $3\frac{1}{2}$ in. × $\frac{1}{2}$ in. The metal in both stem and table is slightly tapered.

Angle and tee sections are also rolled with a thickening at the end of the long side and stem respectively and are termed *bulb* angles and tees.

Bulb flats are also occasionally rolled, as are sections in the form of a *zed*.

Squares are readily obtainable up to 6 in. × 6 in., *rounds* from $\frac{3}{16}$ in. diameter to 8 in., *wire* down to less than $\frac{1}{64}$ in., *flats* up to 18 in., and *universal plates* up to 45 in. width.

Single *plates* are rolled, weighing over 1 ton, and in some cases up to an area of 450 sq. ft.

Plates with a raised chequer on one side, corrugated sheets, many different rail sections, both bull-head and flat-bottomed, special sections for window sashes, reinforcing rods, and other purposes, must all be included in the list of material available for the structural engineer.

A special *trough* section, much used for bridge flooring, riveted together with or without intermediate flats, as shown in Fig. 48, is made

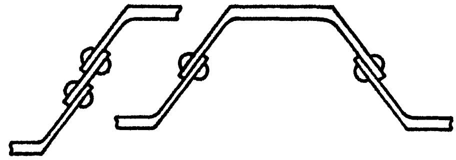


FIG. 48

by Messrs. Dorman, Long & Co. in several different sizes.

Sections of greater thickness than standard can be produced by moving the rolls farther apart, though a sufficiently large order to justify a special rolling must be placed with the mills if the cost for such increased sections is not to be prohibitive.

Fig. 49[1] shows by the white areas the increase in sections produced by ordinary rolls, and Fig. 50[1] that in broad flange beams.

Margins. It will be obvious that slight variations in the finished sections must be allowed for, and a tolerance of $2\frac{1}{2}$ per cent over or under the specified weight is commonly permitted.

Similarly, in ordering specified lengths of a section, a margin of 1 in. under or over is permitted, but an accuracy of $\frac{1}{8}$ in. over or under is obtainable at an extra cost.

Structural Properties. The reader is referred to the lists published by the British Standards Institution, and given in structural steel handbooks, for the properties of the various sections available. These will include dimensions, area, weight per foot run, position of centroid, direction of axis for maximum moment of inertia, if there is no axis of symmetry, moments of inertia and section moduli about two axes, and radii of gyration.

There will also be found tabulated the safe distributed loads for a certain stress ($7\frac{1}{2}$ or 8 tons per square inch) for varying spans, and sometimes the corresponding central deflections,

Stanchion and strut loads are also tabulated, but the values of these vary with the column formula adopted.

[1] See note on page 1447

GIRDERS: PLAIN AND PLATED

Flange Width. A long girder may fail by side bending of the top flange before the tension yield point has been reached in the bottom flange.

Many formulae have been devised for the safe top flange stress for various ratios of unsupported length to flange breadth. That given in B.S.S. 449 is (11–0·15 l/b) tons per sq. in., where l is the unsupported length, which must not exceed 50 times the breadth (b). The formula is not applicable for ratios of l/b less than 20, for which the stress allowed on the net section is 8 tons per sq. in. This formula was published in 1927 by the Institution of Structural Engineers in Part I of its Report on Steelwork for Building.

In the Report as revised in 1933, this has been amended to $8\left[1-\frac{1}{500}\left(\frac{l}{g}-90\right)\right]$, where g is the radius of gyration of the top flange and permits values up to $\frac{l}{g} = 400$.

For steel joists, the g of the top flange will not be less than $\frac{b}{5}$, so that this revised formula permits a stress of more than 3 tons per square inch for $l/b = 80$.

If the top flange is stiffened by a concrete casing not less than 2 in. thick, it is recommended that the breadth (b) in the formula should be taken as the breadth of the steel flange plus the casing thickness on one side only with a maximum of 4 in.

In bridges where the floor is carried on the bottom flange, the stay to the top flange is often provided by stiff brackets connecting the top flange to the cross girders.

Pairs of Plain Beams. In selecting a girder of a required section modulus, it is economical to avoid plating, and if a single plain section is not available, to choose two plain sections connected by bolts passing through *separators.* These may be of cast iron, similar to those illustrated. Frequently gas pipes are used, and steel channels make good separators.

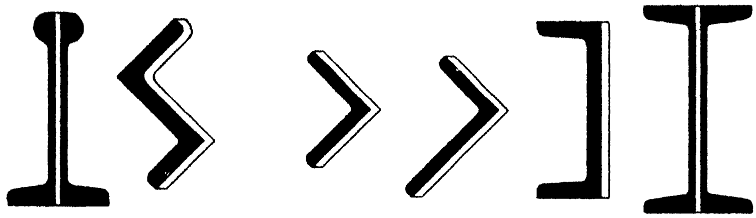


FIG. 49

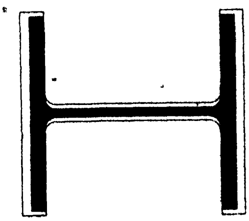


FIG. 50

Compound Girders. If the required section modulus is unobtainable in plain sections of the depth desired, it may be necessary to use one, two or three plain joists (or two channels), with their flange areas increased by plates riveted to them, as shown in Fig. 54.

The moment of inertia of such compound sections can be calculated in the way shown on page 1413, and the section modulus obtained by dividing by the neutral axis distance.

It is usual to have the same size plates top and bottom, which makes the cross-section symmetrical about the neutral axis.

The area of the rivet holes in a cross-section (the product of the flange thickness, the diameter of the rivet $+\frac{1}{16}$ in., and the number of rivets) must be deducted from the area of the tension flange; but in the compression flange, if the rivets completely fill the holes, as they should, there is no loss of compressive section thereby.

To simplify calculation, however, it is usual to assume that both top and bottom flanges are similarly reduced in effective area, the result being that the actual stress in the top flange is less than that calculated.

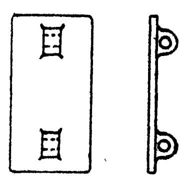


FIG. 51

The section modulus of two plates each of area $b \times t$ a distance d_1 apart (see Fig. 53) is readily obtained as follows: $I = \frac{b}{12}(d_2^3 - d_1^3)$ $\doteq \frac{b}{12}(d_2 - d_1) \times (d_2^2 + d_1 d_2 + d_1^2) = \frac{b}{12} \times 2t \times 3d_1 d_2$ very nearly for the relative sizes of d and t occurring in practice; therefore $M = b{\cdot}t{\cdot}d_1 =$ area of one plate $\times$ distance between the plates. (44)

Thus the section modulus of a 16 in. joist plated with 8 in. × ½ in. plates top and bottom will be increased by 2 × ½ × 16 = 16 in.³ if the plate width is increased from 8 in. to 10 in.

The reduction in section modulus due to a hole through a flange is similarly the product of

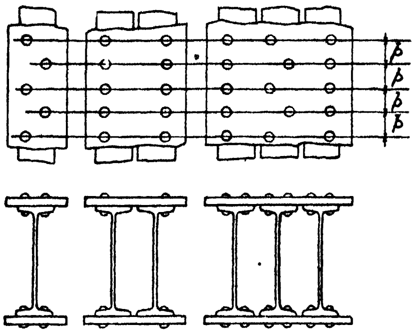


FIG. 52

flange thickness, hole diameter, and distance between the flanges.

If M_1 is the original net section modulus of the unplated girder of depth d_1, and M_2 is the required net section modulus of the plated girder of depth d_2, then

$M_2 = \frac{M_1 d_1}{d_2} + A \cdot d_1$, where A is the net area of the plates on each flange.

$$\therefore \quad A = \frac{M_2}{d_1} - \frac{M_1}{d_2} \tag{45}$$

Thus if the gross section modulus of a 16 in. R.S.J. = 77·3 in.³,
the modulus of a 15/16 in. diameter hole, one in each flange ¾ in. thick = 15/16 in. × ¾ in. × (16 − 1½) = 10·2 in.,

net section modulus. = 67·1 in.,

If the required modulus is 205, the net area of plates 1 in. thick on each flange will be $\frac{205}{16} - \frac{67 \cdot 1}{18}$ = 12·8 − 3·7 = 9·1, and a 10 in. plate will be suitable.

As the required section modulus is at a maximum only for a short distance, an economy may be effected by cutting the plates short.

The theoretical points where plates can be stopped can be found by constructing the section modulus diagram, which will be identical with the bending moment diagram to a different scale. On this diagram can be drawn horizontal lines at a distance from the base representing the values of the section moduli of the girder with 1, 2, 3, etc., plates; the points of intersection will indicate the points where the section may be reduced by the area of one plate.

It is usual to extend the plates about three pitches of rivets beyond the theoretical stopping-off points, and to extend the plates next to the joist right to the end of the girder.

B.S.S. 449 limits the longitudinal pitch of rivets to 16 times the thickness of the thinnest outside plate or angle with a maximum of 6 in. in compression flanges and 8 in. in tension flanges, except that if two rows of staggered rivets are placed in one flange angle the straight line pitch in the direction of stress may exceed the values given by 50 per cent.

In addition, the projection of the plates beyond the outside line of rivets is limited to 9 times the thickness of the *thinnest outside plate* (t), except that when tacking rivets connecting two or more flange plates are used the projection may be increased from $9t$ to $12t$. The pitch of such tacking rivets must not exceed $24t$ or 12 in.

The whole section (30), however, of B.S.S. 449 should be studied carefully, as representative of best modern practice.

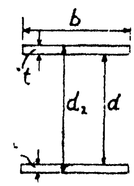


FIG. 53

Plate and Box Girders. For deep girders it is sometimes necessary to build up a section of plates and angles.

When two or more web plates are used the resulting beam is known as a *box girder*.

As some specifications call for different stresses in tension and compression, the flanges are sometimes of different section.

Plate Girders can be designed on the same section modulus method as for compound girders, but more often the resistance moment is taken as the load carried by each flange (area multiplied by working stress), multiplied by the distances between their centres of gravity.

Usually one-eighth of the web area is reckoned as acting with the flange for resisting longitudinal stresses.

For finding the theoretical length of the flange plates, a flange area diagram is constructed and horizontal lines drawn thereon, the distance between the lines representing the areas of the component parts. This method assumes a constant distance between the centroids of the flange areas, the error in this assumption not being great for deep girders.

If the flange area includes one-eighth of the web area, the pitch will be increased in the proportion of the area of the flange plus one-

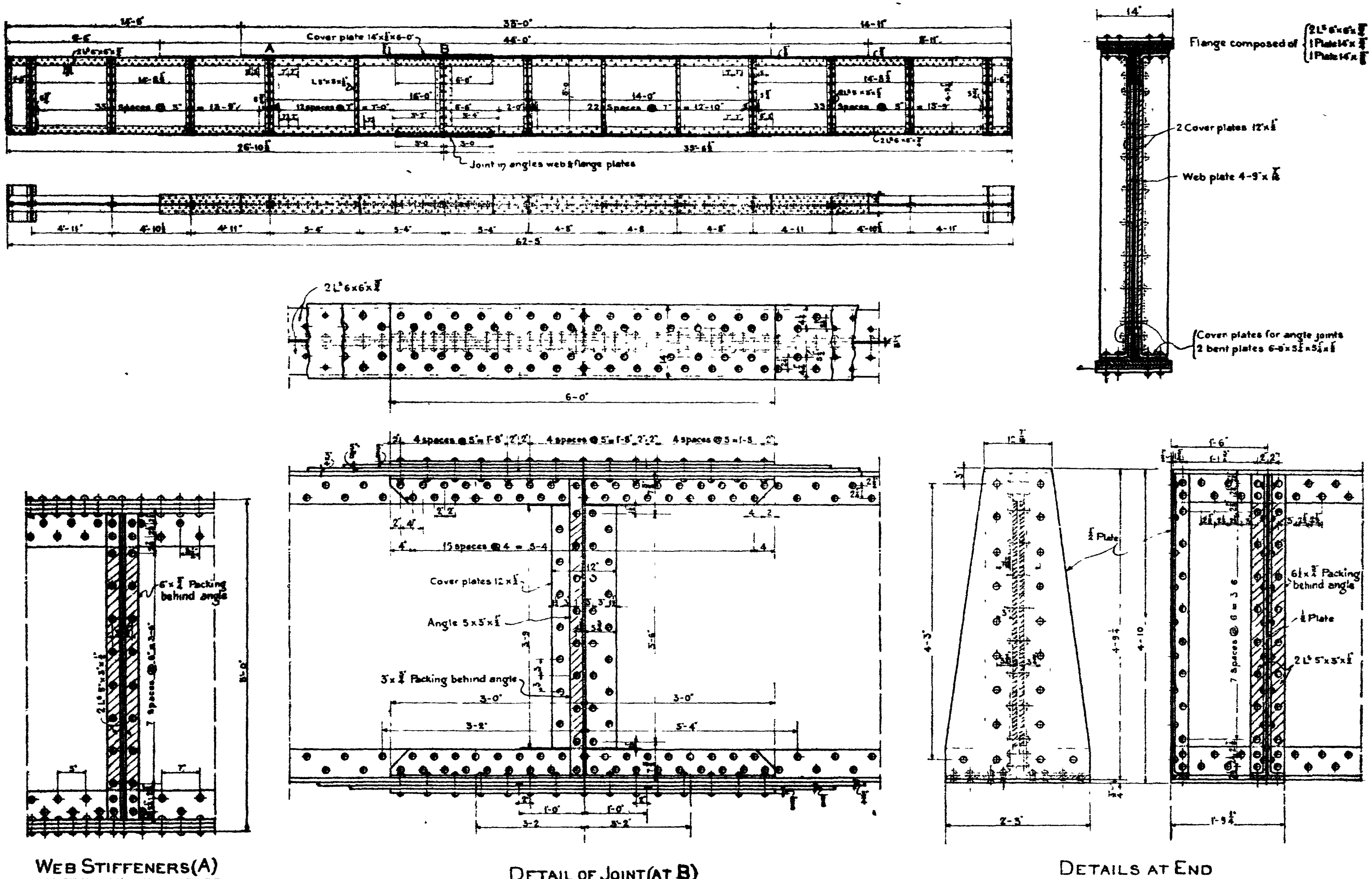
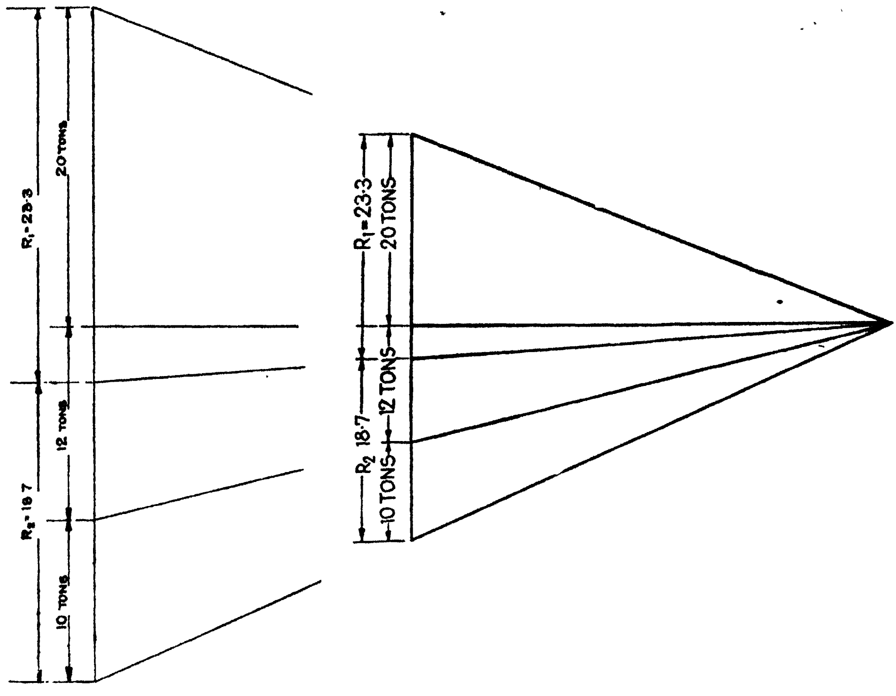
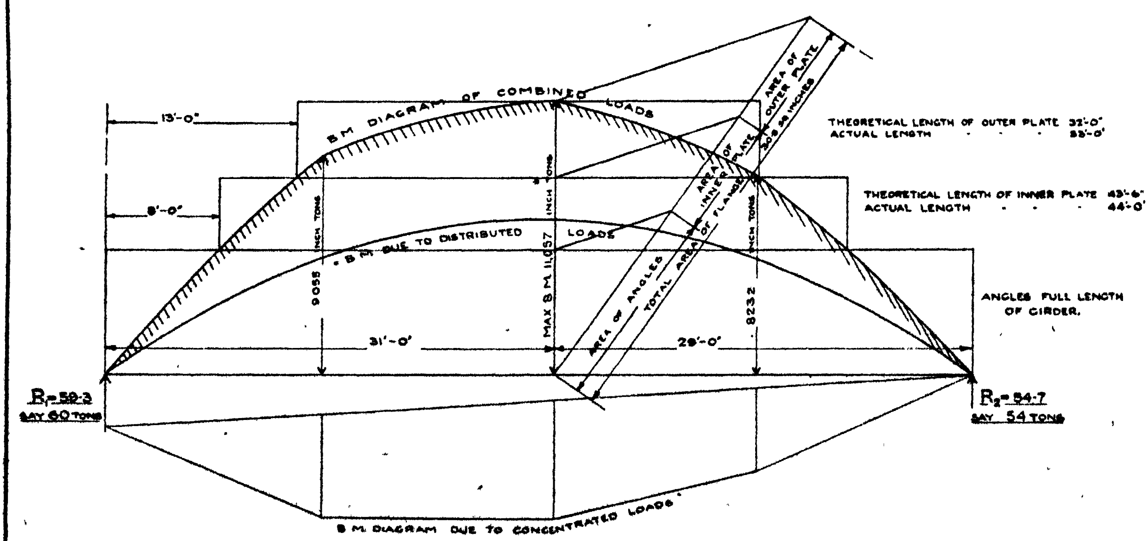


Fig. 54. Design for Plate Girder, 60ft. Span



POLAR DIAGRAM FOR CONCENTRATED LOADS



BENDING MOMENT DIAGRAM

eighth the web area, to the area of the flange, as the load in one-eighth of the web will not pass to the flange through the rivets.

Covers. It may be necessary to make up the length of a plate or angle in two or more pieces, in which case extra material must be employed to give the sectional area lost by the joint.

B.S.S. 449 specifies an excess area of 5 per cent for symmetrical covers, and 10 per cent for non-symmetrical covers. There must be sufficient rivets through the cover on each side of the joint to develop the strength of the jointed member.

EXAMPLE. Design a plate girder, 60 ft. span, to carry a uniformly distributed load of 1 ton per foot, and point loads of 20 tons, 12 tons, and 10 tons at distances of 15 ft., 31 ft., and 45 ft from the left-hand end. The conditions are bad and will make painting difficult. For this reason use a safe stress of only 6 tons per square inch in tension.

$$= \left(\frac{150 + 348 + 900}{60}\right) + \frac{72}{2} = \left(\frac{1398}{60}\right) + \frac{72}{2}$$

$= 59{\cdot}3$, say 60 tons

RIGHT-HAND REACTION

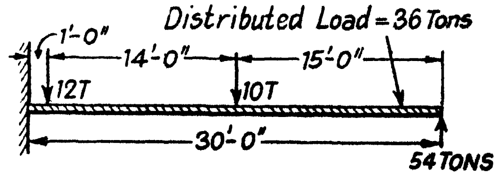
$(10 + 12 + 20 + 72) - 60$

Total load − left-hand reaction

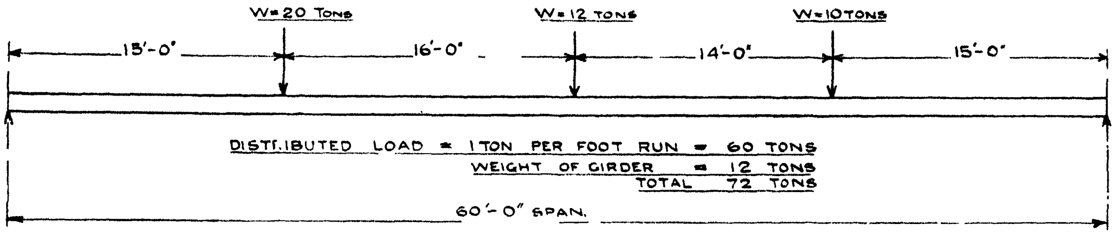
$= 114 - 60 =$ say, $54{\cdot}0$ tons

Bending moment must be either under one of the loads or between centre of girder and one load.

At centre of girder bending moment =



$= (12 \times 1 \times 12'') + (10 \times 15 \times 12)$
$\quad + (36 \times 15 \times 12) - (54 \times 30 \times 12)$
$= 144 + 1800 + 6480 - 19440$
$= 8424 - 19440 = 11016$ in.-tons



DESIGN FOR PLATE GIRDER, 60 FT. SPAN, CARRYING DISTRIBUTED LOAD OF 1 TON PER FOOT RUN AND POINT LOADS AS SHOWN

SOLUTION. *Weight of girder may be*

$$w = \frac{l \times \text{span in feet}}{520}$$

when l = Load on girder in tons (not including weight of girder)

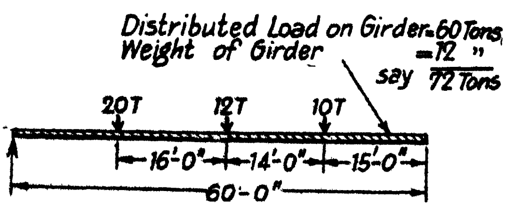
520 = Constant

w = Weight of girder in tons

$l = (20 + 12 + 10) + (1 \times 60)$
$= 20 + 12 + 10 + 60$
$= 102$ tons

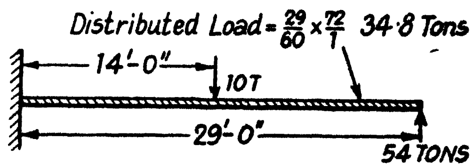
from which $w = \dfrac{102 \times 60}{520}$ = say 12 tons

Reactions. LEFT-HAND REACTION may be calculated by taking moments about right-hand support.



$$= \frac{(10 \times 15) + (12 \times 29) + (20 \times 45)}{60} + \frac{72}{2}$$

Under the 12-ton load



$= (54 \times 29 \times 12) - \{(10 \times 14 \times 12)$
$\quad + (34{\cdot}8 \times 14{\cdot}5 \times 12)\}$
$= 18792 - \{1680 + 6055\}$
$= 18792 - 7735 = 11057$ in.-tons

It is sufficiently near to take position of maximum bending moment as being under the 12-ton load.

Then maximum bending moment on girder

$= 11057$ in.-tons

Bending moment under loads will be taken from bending moment diagram.

Assuming a depth of girder of one-twelfth of the span, then depth over flange plates at centre of girder

$$= \frac{60 \text{ ft.}}{12} = 5 \text{ ft.} = 60 \text{ in.}$$

Area of flange required under 12-ton load

(Allow f_s of 6 tons)

$$= \frac{\text{Maximum bending moment}}{\text{Depth of girder in inches} \times f_s} = \frac{11057}{60 \times 6} = \frac{11057}{360}$$

= 30·8 sq. in. (net area of flange)

Angles should be at least one-half total area of flange.

Therefore angles require area of, say, 15 sq. in. net

Net area of two angles 6 in. × 6 in. × $\frac{3}{4}$ in. (with two holes 1 in. diameter out of each)

$= 2(8{\cdot}44 - 2 \times 1 \times \frac{3}{4}) = 2(8{\cdot}44 - 1{\cdot}5)$
$= 2 \times 7 = 14$ sq. in. approx.

Area of flange plates

= Total area — Area of angles
= 30·8 — 14 = 16·8 sq. in.

Use, Inner plate 14 in. × $\frac{3}{4}$ in. net area	9·0 sq. in.	
Outer plate 14 in. × $\frac{5}{8}$ in. net area	7·5 „	
Total	16·5 „	

Length of inner plate (from diagram), say 44 ft.
Length of outer plate (from diagram), say 33 ft.

Thickness of web plate

(Allow shear stress of $2\frac{1}{2}$ tons per sq. in.)

$$= \frac{\text{Total shear} = \text{(maximum reaction)}}{\text{Depth of girder in inches} \times f_s} = \frac{59{\cdot}3}{60 \times 2\frac{1}{2}\text{ tons}}$$

= ·4 in., say, $\frac{7}{16}$ in. web

EXAMPLE. A built-up girder of uniform cross-section is to carry a uniformly distributed load over a span of 70 ft., and the deflection in the centre is not to exceed $\frac{1}{400}$ of span.

Determine the necessary depth of the girder if the maximum intensity of stress is not to exceed 8 tons per square inch, and modulus of elasticity is 13,000. If the uniform load is $1\frac{1}{2}$ tons per foot run including the weight of beam itself, determine the moment of inertia required.

Design a suitable section at the centre of span. Use 6 in. × 6 in. × $\frac{1}{2}$ in. flange angles, and make the flange plates 14 in. wide. Neglect the effect of rivet holes and web plate.

SOLUTION. The deflection at the centre of a uniformly loaded beam with simply supported ends is

$$\text{Deflection} = \frac{5WL^3}{384EI} = \frac{L}{400}$$

where W is the total load on girder = $1\frac{1}{2}$ tons × 70 ft. = 105 tons.

L is the span = 70 ft. × 12 = 840 in.

E is the modulus of elasticity = 13,000 tons per sq. in.

I is the moment of inertia at centre of span.

$$\text{Therefore} \quad \frac{5 \times 105 \times 840^3}{384 \times 13{,}000 \times I} = \frac{840}{400}$$

$$\text{from which } I = \frac{5 \times 105 \times 840^3 \times 400}{384 \times 13{,}000 \times 840}$$

= 30,000 in. approximately

$$\text{Now} \quad \frac{M}{I} = \frac{f}{y}$$

where M is the bending moment at centre of span

$$= \frac{WL}{8} = \frac{105 \times 840}{8} = 11{,}000 \text{ inch-tons}$$

I is the moment of inertia of section at centre of span = 30,000.

f is the maximum stress = 8 tons per sq. in.

y is the distance from neutral axis to outside fibre.

$$\text{Therefore } y = \frac{fI}{M} = \frac{8 \times 30{,}000}{11{,}000} = \text{say, } 22 \text{ in.}$$

Total depth of beam will be twice this

$2 \times 22 = 44$ in.

Assume this to be outside of flange angles and centre of gravity of flange as a whole.

A good rule to find a closely approximate size of section is

$$RM = f \times A \times d$$

where RM = resisting moment of section = at least the bending moment of 11,000 inch-tons.

A is the area of one flange of girder, i.e. the area of two angles 6 in. × 6 in. × $\frac{1}{2}$ in. plus area of flange plates (rivet holes and web plate to be neglected).

d is depth of girder, which can taken at 44 in.

Therefore

$$A = \frac{BM}{f \times d} = \frac{11{,}000}{8 \times 44} = \frac{11{,}000}{352} = 31 \text{ sq. in.}$$

Two angles 6 in. × 6 in. × $\frac{1}{2}$ in. have an area of

$2 \times 5{\cdot}75 = 11{\cdot}5$ sq. in.

Therefore the flange plates must have an area of

$31 - 11{\cdot}5 = 19{\cdot}5$ sq. in.

The flange plates are to be 14 in. wide, therefore

$$\text{thickness of plates} = \frac{19{\cdot}5}{14} = 1{\cdot}4 \text{ in.}$$

This thickness could be obtained by using two plates, one $\frac{5}{8}$ in. thick and one $\frac{3}{4}$ in. thick, the total thickness being nearly 1·4 in.

Note. (The deflection of $\frac{1}{400}$ of the span on a span of 70 ft. is more than 2 in. If headroom is not important it might be possible to use a deeper beam which would give less deflection) Generally speaking, good practice uses a depth of about $\frac{1}{12}$ span for plate girders over 50 ft. span. In many cases of competitive design a portion of the web is assumed to resist bending stresses, and resisting moment is taken as

$$RM = f\left(A + \frac{W}{8}\right) \times d \text{ where } W \text{ is area of web.}$$

Stiffeners. Stiffeners are intended to prevent web buckling due to compressive stresses, to prevent lateral failure of the compression flange, to relieve the rivets connecting the flange to the web by transferring load direct, to reduce the vertical stresses on horizontal planes in the web due to concentrated loads, and to help hold the web true to shape during manufacture and erection.

The combined effect of shear and longitudinal stress is to produce inclined compressions and tensions at right angles to one another. At the neutral axis these stresses are at 45° with the axis. The compressive stresses tend to buckle the web, and attempts have been made to derive a column formula for the safe web stresses with varying ratios of unstiffened dimensions to web thickness, taking into consideration the fact

that web plates, of a thickness one-sixtieth of the depth between flange angles, have proved satisfactory for a shear stress of 5 tons per sq. in. on the gross section.

At *A* there is a packing piece (shown shaded) between the stiffener and the web. This allows the stiffeners to be made straight. In all cases the stiffener angles should fit tight

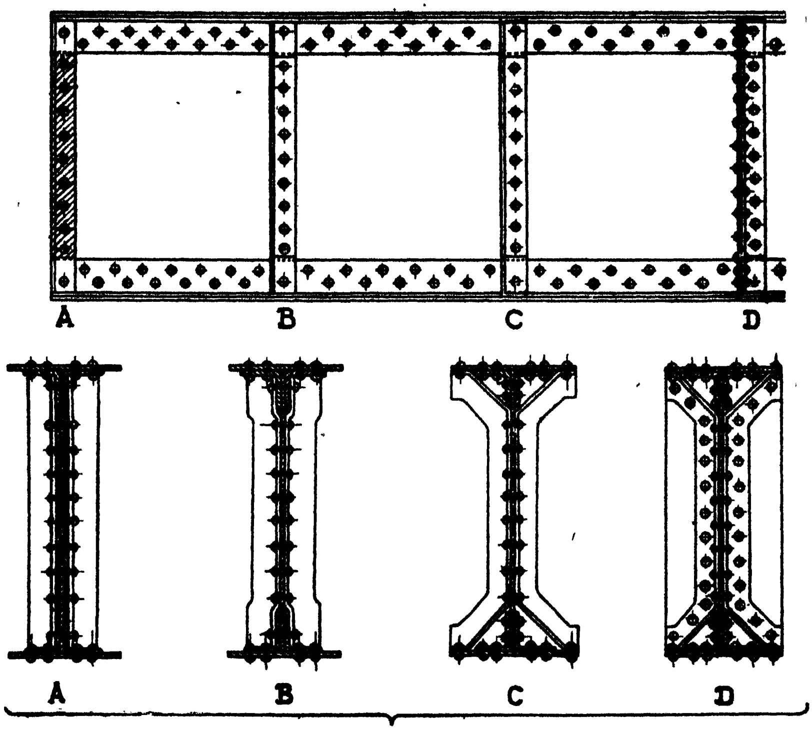


FIG. 55

There is no universally accepted practice for stiffener design. It is usual to put stiffeners at the supports, under concentrated loads, and intermediately at distances apart not greater than 60 times the web thickness, or 6 ft. B.S.S. 449 specifies that they shall be designed as struts[1] of a length three-quarters of the girder depth to carry the whole vertical shear at the supports, and two-thirds of the shear at intermediate points.

Fig. 55 shows various types of web stiffener.

Here we show the elevations and sections of four different types of stiffeners.

[1] Columns and struts are discussed in a later chapter.

against the outstanding legs of the flange angles. At *B* a detail shows that the stiffener angles are bent or joggled as they fit round the flange angles.

Now notice the different type *C*. Here the flange plates are wide and there is sufficient space to get rivets on the outside of the angles. This type of stiffener is expensive, but makes a good job. Somewhat similar is the type *D*. Here we have vertical plates in addition to the angles. In Fig. 54 other types of girder stiffeners are shown.

In welded girders the stiffeners are often made of flat bars.

Chapter VIII—COMPRESSION MEMBERS

Euler's Formula. If a straight flexible steel rod with pointed ends is put under a sliding block free to move vertically only, it will hold it up, provided that the weight of the block is sufficiently small. When the rod is bent by transverse pressure at its centre the block will sink, but will rise again when the rod straightens on the removal of the transverse pressure. If weights are added gradually to the block and the rod bent after each addition, the rod will straighten less readily on removal of the side pressure, and a point will be reached when the rod will remain bent but still hold up the block.

As the vertical load (P) must be transmitted through the pointed ends of the rod, the bending moment at any point in the rod must be the product of the load and the deflection, that is, the shape of the bending moment and deflection curves is the same.

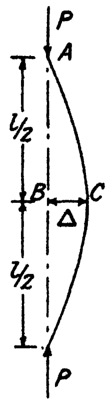


FIG. 56

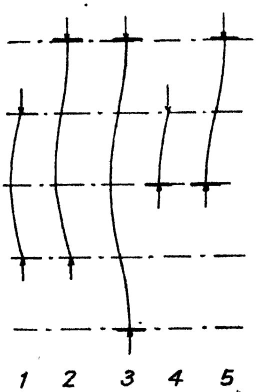


FIG. 57

From the relationship existing between the bending moment and elastic curves (see Chapter IV) the curve in question must be the *curve of sines*, that is, if the central deflection is Δ, the deflection at any point a distance x from the end is $\Delta \times \sin\left(\frac{x}{\frac{1}{2}l} \times 90^\circ\right)$. It will be noted in Fig. 56 that l is the vertical distance between the ends of the bent rod. This will be the same as the length of the rod only when Δ is very small.

As the area of the curved triangle ABC $\frac{2}{\pi} \times \frac{l}{2} \times \Delta$ and its centroid is $\frac{2}{\pi} \times \frac{l}{2}$ from A, the central deflection

$$\Delta = P \times \frac{2}{\pi} \times \frac{l}{2} \times \Delta \times \frac{2}{\pi} \times \frac{l}{2} \div E \cdot I \quad . \; (48)$$

$\frac{2}{\pi} = \cdot 637$ corresponds to $\frac{2}{3} = \cdot 667$ for the area of a parabolic triangle and to $\frac{5}{8} = \cdot 625$ for the centroidal distance from the apex (*see* Fig. 23, page 1422).

If A = the area of the rod and f_c is the compressive stress due to the load P, $I = A \cdot g^2$ and $P = A \cdot f_c$, and equation (48) simplifies to

$$f_c = E \cdot \pi^2 \div \left(\frac{l}{g}\right)^2 \quad . \quad . \quad (49)$$

This is the value deduced by Euler for the crippling stress on an initially straight strut with no directional restraint at the ends. It is independent of the deflection, which must be very small if l is to represent the length of the strut.

If one end is fixed in direction as well as position, the theoretical crippling stress is for a strut 50 per cent longer, as shown in Fig. 57, 2. If both ends are fixed, the theoretical crippling stress is for a strut twice as long (Fig. 57, 3). If one end is fixed and the other free to move, the length for the same crippling stress is only half that of the strut first considered (Fig. 57, 4). If both ends are fixed in direction only, the length for the same crippling stress will be the same as if the ends had no directional restraint (Fig. 57, 5).

It will thus be evident that the condition of the ends of a compression member has an important effect on the theoretical crippling stress.

The ends of the strut first considered (Fig. 57, 1) are termed *hinged*, *pin jointed*, or *pin connected*. Those indicated in Fig. 57, 3, are termed *fixed*, though in actual practice there are degrees of fixity difficult to define.

Euler's crippling stress was deduced from considerations of elastic deflection, and, therefore, cannot hold good when the elastic limit in compression is reached. If the values given by Euler are plotted as shown in the full line curve,

Fig. 58, the curve must be cut off at the elastic limit and higher values discarded.

Rarely, however, does a strut behave in a way that a perfectly straight and perfectly homogenous strut should.

Owing to slight inequalities in elastic properties in different portions of the section, an

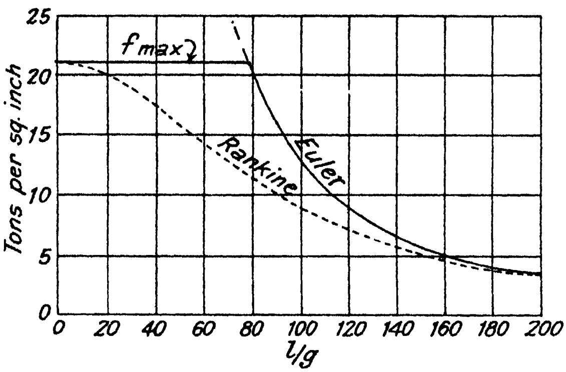


FIG. 58

axial pressure causes lateral deflection to start at low loads, and it is rare for a strut itself to be without some initial deflection which will increase as the load increases, and tests may be expected to indicate crippling stresses less than the theoretical, but not less than values indicated by some such line as that shown dotted in the figure.

Rankine's Formula. Considerable ingenuity has been shown and an immense amount written in the endeavour to devise a formula for a curve, applicable in practice, which will agree with the lower limits of tests. Tests, however, show such a wide range that many such formulae can be considered equally satisfactory. Many take the form of Rankine's formula

$$f_c = f_{max} \div (1 + k \cdot l^2/g^2) \quad . \quad . \quad (50)$$

where f_c = crippling stress, and the values of f_{max} and k are chosen to approximate to the lower limits of tests.

Unsuccessful attempts have been made to reconcile this formula with theory on the following lines. With a deflection $\triangle$ either actual in a homogeneous strut, or that which would produce the same effect as inequalities in the elastic properties of a non-homogeneous material, the maximum stress in a cross-section $f_{max} = f_a + f_b$, where f_a = the axial stress (P/A), and f_b = the bending stress $= Bn \div I = P \cdot \triangle \cdot n \div A \cdot g^2 = f_a \cdot \triangle \cdot n \div g^2$. Therefore

$$f_{max} = f_a(1 + \triangle \cdot n \div g^2) \quad . \quad . \quad (51)$$

As the deflection in a transversely loaded strut is proportional to l^2/n, for $\triangle$ may be substituted kl^2/n, and equation (50) results. As, however, the deflection is also proportional to the bending stress, k cannot be a constant if the formula is to agree with theory.

Values for f_{max} and k in Rankine's formula, commonly employed in this country, are given in Table XVI. The crippling loads given thereby are for hinged ends.

For a detailed discussion of the many formulae which have been proposed, the reader is referred to Dr. E. H. Salmon's *Columns*, from which the values in Table XVI have been taken.

TABLE XVI

VALUES FOR USE IN RANKINE'S FORMULA

Material	f_{max} (per sq. in.) lb.	f_{max} (per sq. in.) tons	k
Cast iron	80,000	36	1/1600
Wrought iron	36,000	16	1/9000
Mild steel	48,000	21	1/7500
Strong timber	7,200	3	1/750

The structural engineer is usually more concerned with the safe working stress than with the crippling load. The former is deduced from the latter by dividing by a safety factor, which may be constant or increase with the ratio l/g. The values so obtained are usually given for both ends fixed.

One of the problems that arises when young engineers begin to use the L.C.C. code of practise formula is the way in which the "effective length" should be used.

Generally the loads designed for are larger than those which come on to the columns and beams, especially in the case of wind loads. Again, although the steel framework (in a steel framed building) is designed to carry all loads, the walls, if brick or stone, have a definite strength.

It is safe enough in ordinary cases to assume that if the beams which run to columns are about the same size as the column, and fixed by web cleats, or by string top as well as bottom cleats, that the column is restrained adequately.

As a guide the cases shown (Fig. 59) may be helpful.

Factors for Fixed, Hinged, and Free Ends. For other end conditions Professor Fidler (whose well-known rational formula is somewhat com-

TABLE XVII

FACTORS FOR FIXED, HINGED, AND FREE ENDS

End Connections	Length for Equal Strength		Multiplier of Actual Length to Obtain Equivalent Length for Both Ends Fixed	
	Fidler	(Euler)	Fidler	(Euler)
Both ends fixed .	l	(l)	1	(1)
One end fixed / One end hinged .	$\cdot 8l$	($\cdot 75l$)	$1\frac{1}{4}$	($1\frac{1}{3}$)
Both ends hinged .	$\cdot 6l$	($\cdot 5l$)	$1\frac{2}{3}$	(2)
One end fixed / One end free .	$\cdot 3l$	($\cdot 25l$)	$3\frac{1}{3}$	(4)

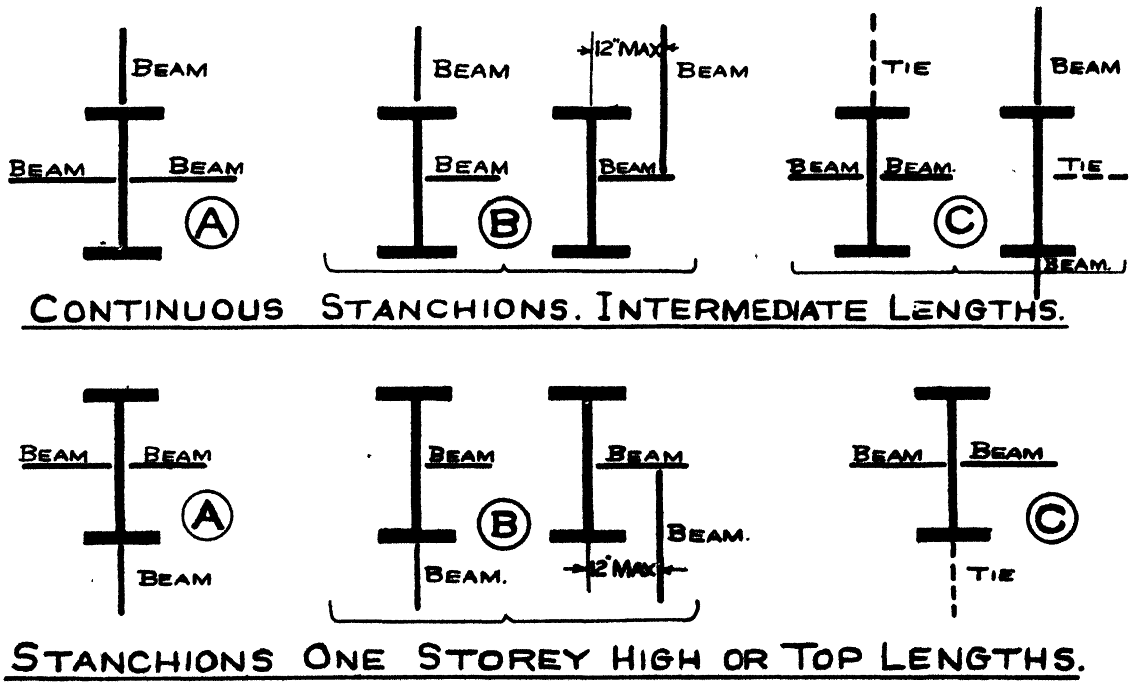
Often, for convenience of calculation, the safe stress curve is represented by a straight line, for which the formula is

$$f = f_1(1 - k \cdot l/g) \quad . \quad . \quad . \quad (52)$$

See, for example, the column formula in Table X, which reduces to this form, as

$$A \cdot d^2/12 = A \cdot g^2 \text{ and } d = g \times \sqrt{12} = 3\cdot 46g$$

NOTES ON THE STRENGTH OF STEEL COLUMNS. In actual steel building construction where the splices and bases are riveted or welded, the perfectly round-ended column which was assumed by Euler does not exist. Tests made on full sized columns during the last forty years



If connections are satisfactory as regards directional restraint, assume following ratios of effective length to actual length of pillars.

	A	B	C
Continuous Intermediate Stanchions .	0·75	0·875	1·00
One Storey or Top Lengths . . .	0·875	1·00	1·25

FIG. 59

plicated, but when the results are once calculated is as easy to apply as any other) recommended the factors given in Table XVII, instead of the theoretical values deducible from Fig. 57, as in practice end fixity will not be complete, and slight rotation of the ends of a strut will usually be possible.

show that the actual breaking load on columns which were tested with pin ends can be as much as 50 per cent more than the value given by Euler. This is because there is always some friction, and that actual theoretical round-ended columns very seldom exist in practice. Columns which are often conceded as having

pin or hinged ends, because only a small base or light beam forms end restraint, have proved to be stronger than the breaking load which would result if Euler's formula was used as a basis. Generally, the slenderness ratio (which is the length of the column divided by the least radius of gyration) is kept well below 200. The Euler formula is not generally used for columns with a slenderness ratio of less than 200, but for conditions where the Euler formula is used it will generally be sound to have a factor of safety of 2.

Rankine-Gordon Formula. If the strength values shown in Table XVI are used, then for modified steel columns with round ends we get

$$\text{Breaking stress} = \frac{21}{1 + \dfrac{1}{7500}\left(\dfrac{l}{g}\right)^2}$$

A condition which more frequently is made in actual practice is that the columns can fairly be conceded as having one end fixed and one free. In such cases, the value of the figure in front of $\left(\dfrac{l}{g}\right)^2$ will be changed.

$$\text{Breaking stress} = \frac{21}{1 + \dfrac{1}{15{,}000}\left(\dfrac{l}{g}\right)^2}$$

In this formula l is the actual length of the column in inches and g is the least radius of gyration. Using these figures, a factor of safety of 3 would give results which are fairly consistent with those used in practice design.

In the U.S.A. the formula most used for the allowable stress in building construction steel work is

$$\text{Safe stress} = \frac{18{,}000}{1 + \dfrac{1}{18{,}000}\left(\dfrac{l}{g}\right)^2}$$

B.S.I. and L.C.C. Code of Practice. In Fig. 60, the values given by somewhat complicated formula of B.S.S. 449 are plotted. The formula is for "hinged ends." For comparison the stresses allowed by the 1909 Act are also shown.

The value l/g is limited to 150 for parts of the main structure and 240 for subsidiary compression members.

The value of l to be used depends on the end conditions.

Thus, if the pillar is adequately restrained at both ends in position and direction, l is taken as three-quarters the actual length of a one-storey pillar or the actual length from floor level to floor level of a pillar continuous through two or more storeys.

If the pillar is adequately restrained at both ends in position only the actual length is to be

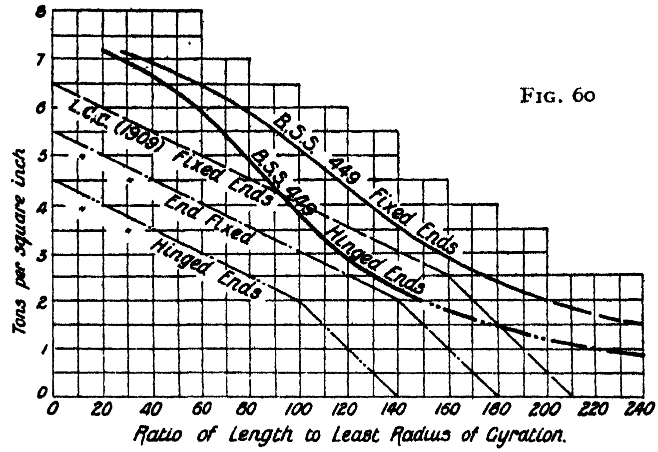


FIG. 60

used for both single storey and continuous pillars, but a less length down to three-quarters the actual can be used for continuous pillars, depending on the degree of directional restraint.

If one end of the pillar is, and the other is not, adequately restrained in both position or direction, the length to be taken varies between the actual length and twice the length, depending on the efficiency of the imperfect restraint.

It will be seen that there are great possibilities of argument as to what constitutes adequate restraint and what value is to be attached to the restraints not completely adequate.

In a book of explanation of the Code,[1] it is stated that if connections are satisfactory from the point of view of directional restraint, the following ratios of effective length to actual length will not be disputed.

For solid steel columns and one-storey stanchions and top lengths of continuous stanchions—

3-way connection or better	$\frac{7}{8}$
2-way connection approximately at right angles	1
1-way connection or 2 in the same line	$1\frac{1}{4}$

For intermediate lengths of continuous stanchion and bottom lengths—

3-way connection or better	$\frac{3}{4}$
2-way connection approximately at right angles	$\frac{7}{8}$
1-way connection or 2 in the same lines	1

[1] *Steelwork in Buildings under the L.C.C. Code of Practice and B.S.S. No.* 449, by D. H. Lee, published by Spon.

EFFECTIVE PILLAR LENGTH

The effective pillar length to be assumed in determining the working load per square inch in accordance with Clause 18 shall be as follows—

	Type of Pillar	Effective Pillar Length
Pillars of one storey.	Adequately restrained at both ends in position and direction.	0·75 of the actual pillar length.
	Adequately restrained at both ends in position but not in direction.	Actual pillar length.
	Adequately restrained at one end in position and direction and imperfectly restrained in both position and direction at the other end.	A value intermediate between the actual pillar length and twice that length, depending upon the efficiency of the imperfect restraint.
Pillars continuing through two or more storeys.	Adequately restrained at both ends in position and direction.	0·75 of the distance from floor level to floor level.
	Adequately restrained at both ends in position and imperfectly restrained in direction at one or both ends.	A value intermediate between 0·75 and 1·00 of the distance from floor level to floor (or roof) level, depending upon the efficiency of the directional restraint.
	Adequately restrained at one end in position and direction and imperfectly restrained in both position and direction at the other end.	A value intermediate between the distance from floor level to floor (or roof) level and twice that distance, depending upon the efficiency of the imperfect restraint.

Note. The effective pillar length values given above are in respect of typical cases only, and embody the general principles which should be employed in assessing the appropriate value for any particular pillar.

COLUMNS

L = Effective length of column determined by conditions of end fixing.

R = Least radius of gyration = $\sqrt{\frac{I}{A}}$

Where I is moment of inertia
Where A is area of section.

F = Safe working stress in tons per square inch of section.

$\frac{L}{R}$	F	$\frac{L}{R}$	F	$\frac{L}{R}$	F
30	6·9	110	3·3	190	1·3
40	6·6	120	2·9	200	1·2
50	6·3	130	2·6	210	1·1
60	5·9	140	2·3	220	1·0
70	5·4	150	2·0	Intermediate values by interpolation	
80	4·9	160	1·8		
90	4·3	170	1·6		
100	3·8	180	1·5		

Eccentric Loading. It is usually assumed that in the safe stress formula adopted, allowance has been made for accidental eccentricity of loading due to inequalities of elastic properties of the materials used, and slight deviation from straightness of the column axis brought about in the process of manufacture.

Allowance, however, is made in subsequent

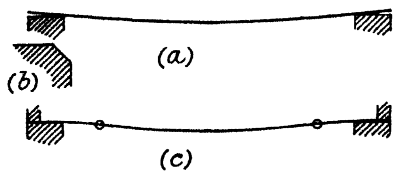


FIG. 61

calculations for intentional eccentricity, though there will always be controversy as to what this allowance should be.

If a beam is carried on a bracket riveted to the side of a stanchion, the load is usually considered as applied at the centre of the bracket.

If a beam is simply supported at the ends on a stiff bearing, any deflection of the beam, will tend to concentrate the load on the edge of the bearing, and if a stone template is used for a heavy load, it is common to chamfer this edge as indicated in Fig. 61 (*b*), to guard against unsightly cracks.

If, in addition to resting on the bracket, the beam has its top flange anchored down by means of (web and) flange cleats, it will not be free to deflect as in Fig. 61 (*a*), but the exaggerated deflection curve will be similar to that shown in Fig. 61 (*c*), with points of contraflexure (indicated by the small circles) some distance from the supports.

The position of these points of contraflexure, and the amount of the restraining moment at the end of the beam which must be supplied by the stanchion, depends on the degree of fixity of the other ends of the stanchion and the relative stiffness of stanchion and beam, the *stiffness* being defined as the *ratio of the moment of inertia to the length* (I/l).

For a slender column carrying a stiff beam, the restraint to the end of the beam will be very small. For a very slender beam with ends rigidly attached to stiff columns, the restraint moment at the ends may be as high as two-thirds of the bending moment in a uniformly loaded unrestrained beam, the bending moment causing sagging in the centre of the beam being only the remaining one-third.

It is usual, however, in steelwork construction not to allow for any relief in mid-span due to end fixity, but to design beams as if they were freely supported on the end bearings.

If the ends are restrained by web and (or) flange cleats, high stresses in these connections may result. These stresses, however, cannot be termed dangerous, as they will be immediately reduced if they exceed the yield point, and cause a slight plastic flow of the metal.

It is common practice to assume that the bending moment in the column, due to the

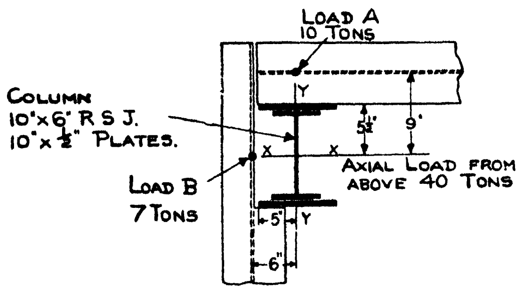


FIG. 62

eccentric reaction of each beam it carries, is the product of the reaction by the distance from the centre of the column to the centre of the bracket supporting the beam.

In the case of a flange connection, the eccentricity is often assumed to be only half the depth of the stanchion over the flanges ($d/2$).

If the column is continuous above and below the girder, half the bending moment is assumed taken by the lower length, and half by the upper; or, if the sections of the two portions differ greatly, the bending moment is assumed as divided between them in proportion to their stiffnesses (I/l).

The load at any floor due to the loads from the floors and roof above, is assumed to be uniformly distributed over the column area, and the only bending moment allowed for (other than for wind) is that due to the eccentricity of the connections at the floor considered.

These assumptions are merely recipes for arriving at suitable sizes, and must not be considered as representing actual conditions.

EXAMPLE. *Eccentrically Loaded Column.* A column formed of one joist 10 in. × 6 in. with one plate 10 in. × ½ in. on each flange is loaded as shown in Fig. 62. Find the equivalent central load and the actual stress per square inch. Also the safe stress using various formulae commonly accepted.

(From tables)

$Ixx = 480{\cdot}7$, $Iyy = 105{\cdot}0$, $Zyy = 21{\cdot}0$
R of $Gxx = 4{\cdot}7$ in., R of $Gyy = 2{\cdot}2$ in.

Axial load = 40 tons.

Eccentric load beam A (10 tons).

$$\text{Equivalent central load} = \frac{A \times E \times y}{R_{xx}^2}$$

where A = Eccentric load = 10 tons.
E = Eccentricity = 9 in.
y = Distance from neutral axis to extreme fibre = $5\frac{1}{2}$ in.
R_{xx} = Radius of gyration = 4·7 in.

$$\text{Equivalent central load} = \frac{10 \times 9 \times 11}{4{\cdot}7 \times 4{\cdot}7 \times 2} = 22{\cdot}4 \text{ tons}$$

Eccentric load beam B (7 tons).

$$\text{Equivalent central load} = \frac{B \times E \times y}{R_{yy}^2}$$

where B = Eccentric load = 7 tons.
E = Eccentricity = 6 in.
y = Distance from neutral axis to extreme fibre = 5 in.
R_{yy} = Radius of gyration = 2·2 in.

$$\text{Equivalent central load} = \frac{7 \times 6 \times 5}{2{\cdot}2 \times 2{\cdot}2} = 43{\cdot}3 \text{ tons}$$

Equivalent central load
$= 40 + 10 + 7 + 22{\cdot}4 + 43{\cdot}3 = 122{\cdot}7$ tons

Stress due to combined loads—

$$\text{Stress} = \frac{\text{Load}}{\text{Area}} = \frac{122{\cdot}7}{21{\cdot}77} = 5{\cdot}64 \text{ tons per sq. in.}$$

Stress by Second Method—

$$\text{Stress} = \frac{W}{A} + \frac{\text{Bending moment}}{\text{Modulus}} = \frac{W}{A} + \frac{BM}{Z}$$

Total load = 40 + 10 + 7 = 57 tons.

$$\text{Unit stress from total load} = \frac{57}{21{\cdot}77} = 2{\cdot}61 \text{ tons per sq. in.}$$

$$\text{Unit fibre stress due to eccentric load (beam } A) = \frac{10 \times 9}{87{\cdot}4} = 1{\cdot}03 \text{ tons per sq. in.}$$

$$\text{Unit fibre stress due to eccentric load (beam } B) = \frac{7 \times 6}{21} = 2{\cdot}00 \text{ tons per sq. in.}$$

Total fibre stress = 5·64 tons per sq. in.

With column 11 ft. high—

$$\frac{\text{Length in inches}}{\text{Least } R. \text{ of } G. \text{ in inches}} = \frac{11 \times 12}{2{\cdot}2} = 60$$

Using formula,

$$\text{Safe stress} = \frac{8{\cdot}0}{1 + \frac{1}{18{,}000}\left(\frac{L}{R}\right)^2} \quad \text{(Amer. I.S.C.)}$$

$= 6{\cdot}7$ tons per sq. in.

$$= 8{\cdot}4 - \frac{L}{22R} \quad \text{(Struct. Comm. 1932)}$$

$= 5{\cdot}7$ tons per sq. in.

$$= 7{\cdot}1 - \frac{L}{32R} \quad \text{(New York)}$$

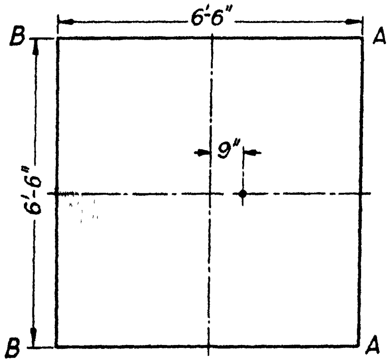
$= 5{\cdot}25$ tons per sq. in.

By approximate formula,

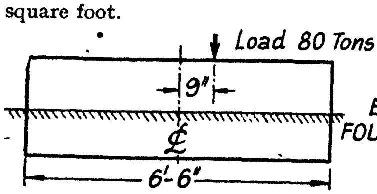
$$\text{Safe stress} = 9 - \frac{1}{2}\left(\frac{L \text{ in feet}}{r \text{ in in.}}\right)$$
$$= 6{\cdot}5 \text{ tons per sq. in.}$$

EXAMPLE.

A stanchion transmits a total load of 80 tons to a concrete foundation block 6 ft. 6 in. square in plan. The centre line of the stanchion lies 9 in. to one side of the centre line of the foundation, as shown in sketch.



Calculate the maximum and minimum pressures on the earth below the foundation in terms of tons per square foot.

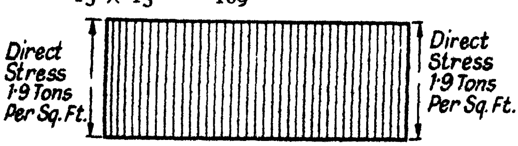


ELEVATION OF FOUNDATION BLOCK

The weight of the block will be neglected as thickness, or depth, is not given.

Direct stress = $80T \div$ Area of block

$$= 80 \div (6{\cdot}5 \text{ ft.} \times 6{\cdot}5 \text{ ft.})$$
$$= \frac{80 \times 2 \times 2}{13 \times 13} = \frac{320}{169} = 1{\cdot}9 \text{ tons per sq. ft.}$$

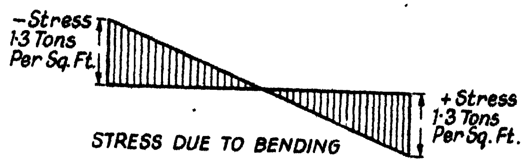


STRESS DUE TO DIRECT COMPRESSION

$$\text{Bending moment} = 80T \times 9 \text{ in.} = 720 \text{ in.-tons}$$
$$= 60 \text{ ft.-tons}$$
$$\text{Modulus} = \frac{B \times D^2}{6} = \frac{13}{2} \times \frac{13}{2} \times \frac{13}{2} \times \frac{1}{6}$$
$$= \frac{2197}{48} = 46 \text{ ft.-units}$$
$$\text{Stress} = \frac{\text{B.M.}}{\text{Mod.}} = \frac{60}{46} = 1{\cdot}3 \text{ tons per sq. ft.}$$

This will be added to direct compression along face AA.

This will be subtracted from compression along face BB.



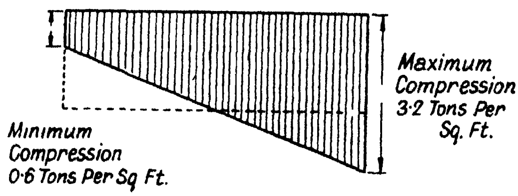
STRESS DUE TO BENDING

Therefore, minimum pressure on earth below foundation will occur along face BB and will be

$$1{\cdot}9 - 1{\cdot}3 = 0{\cdot}6 \text{ ton per sq. ft.}$$

Maximum pressure on earth below foundation will occur along face AA and will be

$$1{\cdot}9 + 1{\cdot}3 = 3{\cdot}2 \text{ tons per sq. ft.}$$



TOTAL COMPRESSION DUE TO DIRECT LOAD AND BENDING STRESSES

We get the same result by using the formula

$$\text{Stress} = \frac{\text{load}}{\text{area}} \pm \frac{\text{bending moment}}{\text{modulus}}$$

The plus or minus sign shows that the stress due to the load being out of centre is greater on one edge than it would be if the load were central, and less on the other edge. In order to ensure that there is no tension or uplift on one edge, the load, or the resultant of the loads, intersects the middle third of the base.

If the load is located 13 in. from the centre, since the total width is 6 ft. 6 in. it follows that if we divide this into three equal lengths, each will be 2 ft. 2 in. The load will therefore be at the edge of middle third.

$$\text{Stress} = \frac{\text{load}}{\text{area}} + \frac{\text{bending moment}}{\text{modulus}}$$
$$= \frac{320}{169} + \frac{80 \times 13}{46 \times 12}$$
$$= 1{\cdot}9 + 1{\cdot}9$$
$$= 3{\cdot}8 \text{ tons per square foot.}$$

Now on the other edge the pressure will be

$$\text{Stress} = \frac{\text{load}}{\text{area}} - \frac{80 \times 13}{46 \times 12}$$
$$= 1{\cdot}9 - 1{\cdot}9 = \text{nil}$$

The pressure would therefore vary from 3·8 tons to 0 tons.

Chapter IX—GRAPHIC STATICS AND FRAMED STRUCTURES

Triangular Frame. To carry a weight W a distance a away from a wall, instead of employing a built-in cantilever beam as indicated in Fig. 18, a framed structure ABC with three pin joints, as shown in Fig. 63, can be used. AB is a tie and CA a strut. If the forces transmitted

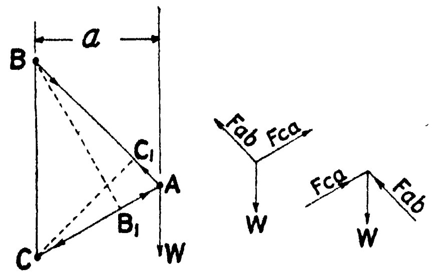


Fig. 63

by them are termed *Fab* and *Fca* respectively, their values can be found by equating the clockwise bending moment due to W with a lever arm a to the counter clockwise bending moment due to the forces *Fab* and *Fca* about B or C. If CC_1 is the perpendicular distance of C from AB, and BB_1 the perpendicular distance of B from CA, the bending moment about C equals $Fab \cdot CC_1$, and that about B equals $Fca \cdot BB_1$.

Therefore

$$Fab \cdot CC_1 = W \cdot a = Fca \cdot BB_1$$

Twice the area of the triangle $ABC = AB \cdot CC_1 = BC \cdot a = CA \cdot BB_1$.

Therefore

$$\frac{Fab \cdot CC_1}{AB \cdot CC_1} = \frac{W \cdot a}{BC \cdot a} = \frac{Fca \cdot BB_1}{CA \cdot BB_1}$$

$$= \frac{Fab}{AB} = \frac{W}{BC} = \frac{Fca}{CA}$$

If, therefore, the load W is represented to some scale by the side BC of the triangle ABC, the two forces in equilibrium with W at the point A are represented in magnitude and direction by the other two sides taken in order, that is *Fca* in the direction CA and *Fab* in the direction AB. This demonstrates the principle of the triangle of forces stated on page 178.

Instead of a strut and a tie the load W could be carried by two ties or two struts of the same magnitude and direction as indicated to the right of Fig. 63.

Funicular and Force Polygons. If, in addition to a load W_1 carried at the point 1 (see Fig. 64), a second load W_2 is carried at the point 2, the magnitude and direction of the force in the strut 23 can be found from the side P, 23 of the force triangle P, 12, 23. Similarly, if a third load W_3 is carried at a point 3, the force in 34 is determined in magnitude and direction from the side P, 34 of the triangle P, 23, 24.

If the points 0 and 4 in the end struts are connected by a tie 04, and the framed structure so formed freely supported at 0 and 4 in such a manner that no movement is possible except in the plane of the structure, then the structure 01234 constitutes a girder supporting the three loads W_1, W_2, and W_3. The structure is in *unstable equilibrium*, as any slight movement will cause it to collapse.

The magnitude of the vertical reactions can be found by drawing P, 04 parallel to the line 04, and thus forming two force triangles P, 01, 04 and P, 04, 34, of which the sides 01, 04, and

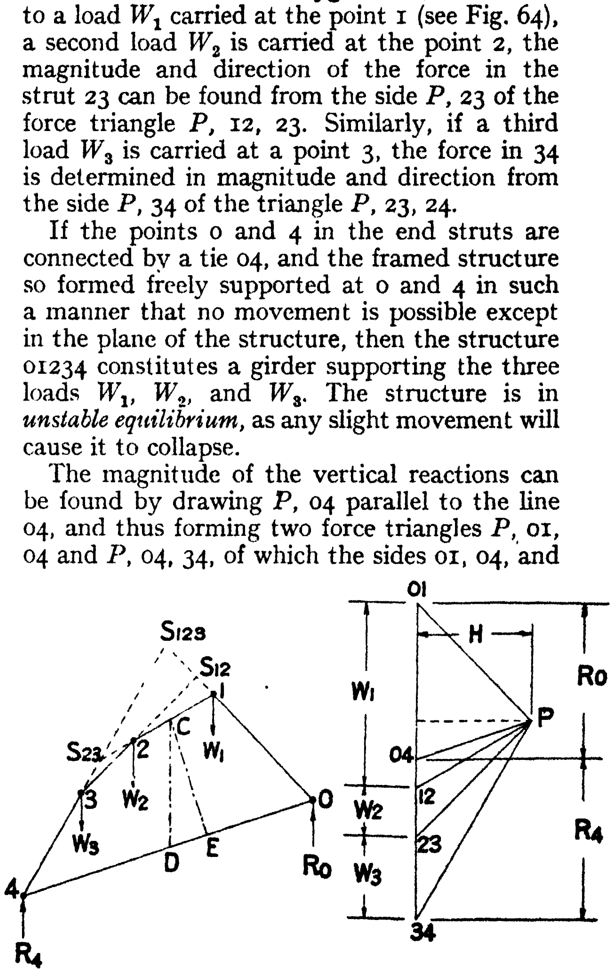


Fig. 64

04, 34 represent respectively the reactions *Ro* and *R4*.

The horizontal component of each of the forces acting in the members of the *funicular*[1]

[1] The word *funicular* is derived from a Latin word meaning *little cord*, but is applied to a structure formed of struts as in Fig. 64 as well as to one formed of ties as in Fig. 65.

polygon, as the frame diagram to the left of Fig. 64 is termed, is represented by H in the right-hand diagram, which is termed the *force polygon*, in which the point P is termed the *pole*.

The frame represented by the funicular will still be in equilibrium if, instead of the reactions being vertical, they are inclined in the directions 01 and 43. In this case there would be no tension in 04, so that the tie it represents could be omitted as in an arch.

Centre of Action of Forces determined Graphically. As all parts of the funicular are in equilibrium, the point $S123$, where the lines 01 and 43 intersect, must be vertically in line with the centre of gravity of the three loads W_1, W_2, and W_3. Similarly, $S12$ is in the line of action of the resultant of W_1 and W_2, and $S23$ in that of W_2 and W_3.

Bending Moment determined from Funicular Polygon. The bending moment due to W_1, W_2, and W_3 at any point in a girder spanning between 0 and 4 can be found directly from the funicular polygon.

If the vertical through the point where the bending moment is to be found cuts the funicular in the line CD, a perpendicular CE can be drawn from C to 04. The bending moment Bc must be the product of the force in 04 and the lever arm CE.

That is, $Bc = P, 04 \times CE$.

As CE is perpendicular to 04 and P, 04, and CD is perpendicular to H, by similar triangles

$$\frac{CD}{CE} = \frac{P, 04}{H}, \therefore CD \times H = P, 04 \times CE = Bc.$$

The vertical intercepts of the funicular polygon, multiplied by H, thus give the bending moment at every point in the span.

Reversal of Stresses in Funicular. If a pole is taken on the other side of the line in the force diagram representing the loads, another funicular polygon can be similarly constructed with the members of the funicular in tension instead of compression, and the closing line of the funicular representing a compression member instead of a tie. The resulting funicular of Fig. 65 could be produced by rotating that of Fig. 64 about a horizontal line, the forces acting in the members being of the same intensity as before but opposite in kind. As before, the long closing line of the funicular can be omitted if inclined reactions are supplied at the supports as in a suspension bridge.

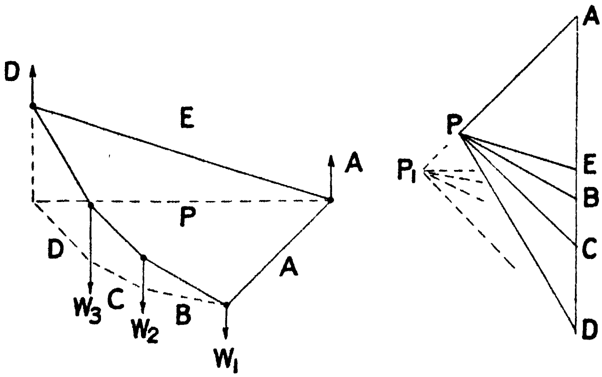


FIG. 65

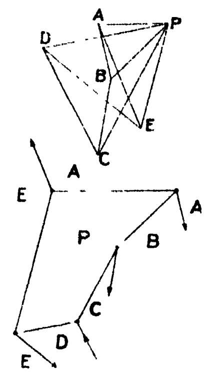


FIG. 66

Adopting Bow's notation, lettering the spaces in the funicular polygon, and placing corresponding letters at the ends of the lines in the force polygon representing the forces, Fig. 65 results.

Effect of Altering Position of Pole. If the closing line of the funicular polygon is required to be horizontal, the pole (P_1) must lie on a horizontal through E. If, in addition, one side of the funicular is to be the line separating the spaces P and A, the pole must also lie on the line PA produced. The funicular polygon and the corresponding force polygon are indicated by the dotted lines in Fig. 65. The funicular polygon in Fig. 65 represents a structure in stable equilibrium, which will return to its original form if the loads carried are moved.

Polygons for Inclined Forces. Though in Figs. 64 and 65 vertical loads have been taken, the method is perfectly general, as will be clear from an inspection of Fig. 66.

The position and direction of the forces AB, BC, CD, and DE are given in the lower diagram, and their direction and magnitude given in the upper diagram.

The resultant of the forces AB and BC in the top figure is represented by the line AC (not drawn); the resultant AB, BC, and CD is similarly represented by the line AD, and that of the four forces by the line AE. The five forces AB, BC, CD, DE, and EA are thus in points and direction of application must be defined. It is usual to assume that the dead loads (which include the weight of the truss itself) are concentrated at points of intersection of the members, which for purposes of analysis are assumed hinged at every joint.

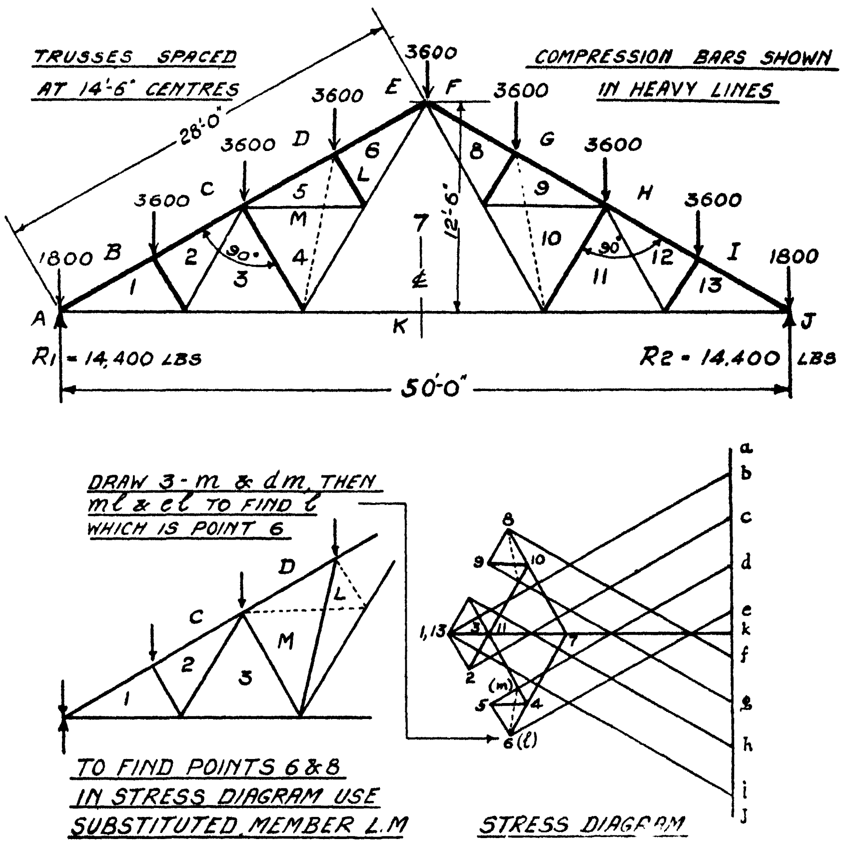


FIG. 67

equilibrium if they act in the direction A to B, B to C, C to D, D to E, and E to A, respectively.

Choosing any pole P and drawing lines PA, PB, etc., in the top diagram, and lines[1] PA, PB, etc., parallel to them in the bottom diagram to intersect the lines of forces at points[1] ABP, BCP, etc., a closed figure surrounding the space P results.

The resultant of the four forces must pass through the point EAP and be parallel to the line AE in the top figure.

Roof Truss Analysis. If it is required to find the forces acting in the various members of a roof truss, the loads to be carried and their

[1] In the notation adopted a line is defined by the letters of two adjacent spaces, and a point by the letters of three adjacent spaces.

In a roof truss the purlins sometimes bear on the rafters between the points of intersection of the members, and produce bending as well as direct stresses in the rafter. Bending stresses are also produced if lines of action of the direct stresses in the members do not meet in a point, and such intentional eccentricities should generally be avoided.

Steel Roof Trusses. Steel roof trusses or principals can be safely designed using vertical loads only. It is not difficult to see that wind pressure, which is assumed to act horizontally, can be resolved into two forces, one acting at right angles to the roof, and one parallel to the roof. The normal force can be resolved into two others, one vertical, and one horizontal. If the

roof truss is assumed to be loaded with a vertical force, due to wind pressure, the stresses will not be very different to those resolved from using the normal wind pressure. The roof truss must be designed to carry its own weight, the weight of the covering, and the wind pressure.

	lb per square ft. of Roof area.
Dead weight of steel truss often works out at about	2½ to 3½
Covering	
Slates, boarding, wood on steel purlins .	14 to 16
Glazing and steel purlins	7 to 9
Corrugated sheets and purlins . . .	4 to 6
Wind pressure for (1 *in* 2) *or* 30° *slopes.* It is near enough to assume results as below—	
30 lb. horizontal wind pressure can be resolved to 20 lb. normal wind pressure; 18 lb. vertical wind pressure	18
Total vertical loads for slated roof, say	38 lb. per sq. ft.
Total vertical loads for glazed roof, say	30 ,, ,,
Total vertical loads for corrugated sheets, say	28 ,, ,,

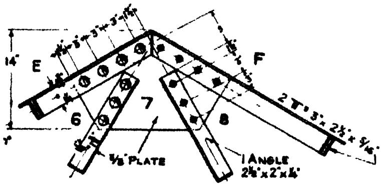
This load will include for the roof truss itself, the purlins, the covering and vertical component of the wind.

Any ordinary steel roof truss which does not carry special weights on the lower chord will be safe if designed for a vertical load of 40 lb. per sq. ft. of ground area covered.

On this basis a roof truss 50 ft. span will now be considered. The trusses are spaced at 14 ft. 6 in. centres.

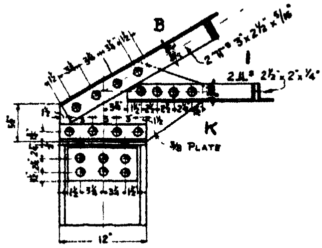
LOADS AT PANEL POINTS. It is easy to see from Fig. 68 that there are seven panel points in addition to the two supports or shoes. At each support the load will be half as much as it is at each of the other points. The load at each panel will be 3,600 lb., and at each shoe 1,800 lb. The 3,600 lb. is arrived at as follows

$$\frac{50}{8} \times \frac{14 \cdot 5}{1} \times \frac{40}{1} = 3{,}600 \text{ lb. approx.}$$



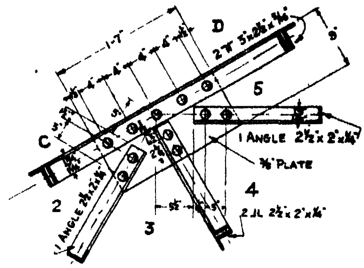
APEX OR CROWN JOINT

FIG 68A



SHOE JOINT

FIG. 68B



MAIN STRUT JOINT

FIG. 68C

The stress diagram can be drawn as shown, but it will be necessary to use a substituted member in order to find point six. The stresses in the various members are shown in the table.

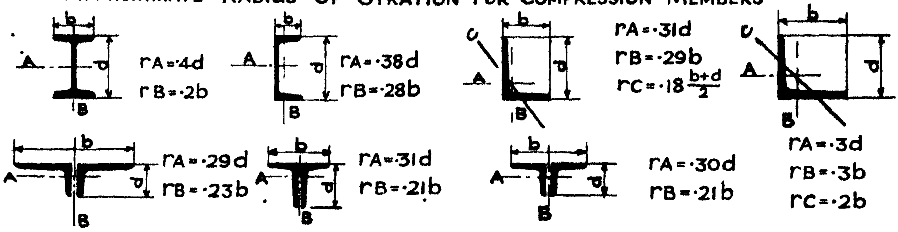
STRESSES IN 50 FT. SPAN ROOF TRUSS
Spaced 14 ft 6 in. apart

Member	Stress	Length Ft.	Length In.	Kind of Stress
B.1 and I.13	11½ tons	7	0	Compression
C.2 and H.12	10½ ,,	7	0	,,
D.5 and G.9	9¾ ,,	7	0	
E 6 and F.8	9 ,,	7	0	,,
3 4 and 10.11	2¾ ,,	7	0	,,
5.6 and 8.9	2¼ ,,	3	6	,,
1 2 and 12.13	2¼ ,,	3	6	,,
5.4 and 9.10	1½ ,,	—		Tension
2.3 and 11.12	1½ ,,	—		,,
6.7 and 8.7	4¼ ,,	—		,,
4.7 and 10.7	2¾ ,,	—		,
K.1 and K.13	10 ,,	—		,,
K.3 and K.11	9 ,,	—		,,
K.7	6 ,,	—		,,

RAFTERS. The maximum stress in the rafters is in member B.1 and amounts to 11½ tons. The length of the member 84 in. Although it may be argued that the rafter is a continuous beam over several supports, the method used in practical designing is to make the rafter suitable for the stress in the lower section (B.1 and I.13) in this case, and make the rafters all the same section. For roof trusses of this type and span, the rafters are almost invariably made of two angles with a space between for the shoe and gusset plates. We will try two angles 3 in. ×

$2\frac{1}{2}$ in. $\times \frac{5}{16}$ in. thick with a space for $\frac{3}{8}$ in. between them. From either a table of approximate values, or from a structural handbook, or by calculation, the value of the radius of gyra-

APPROXIMATE RADIUS OF GYRATION FOR COMPRESSION MEMBERS



tion is found. With the 3 in. leg vertical, the width of the rafter will be $5\frac{3}{8}$ in. The *yy* axis vertical down the middle and the *xx* axis is horizontal. Then, approximate values for radius of gyration for the two angles are

$$Rxx = \cdot 31 \times d$$

$$Ryy = \cdot 21 \times b$$

Where d is the depth, in this case 3 in., and b is the width, in this case $5\frac{3}{8}$ in.

Then $\quad Rxx = \cdot 31 \times d = 0{\cdot}93$ in.

$$Ryy = \cdot 21 \times 5{\cdot}3 = 1{\cdot}1 \text{ in.}$$

From the table of stresses it will be seen that the stress in member (B.1) and (I.13) is $11\frac{1}{2}$ tons.

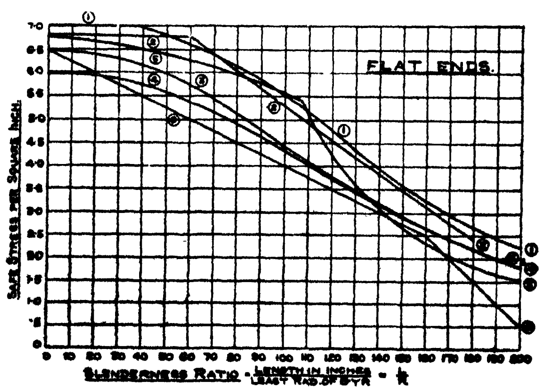


FIG. 69

Curve No. 1 is based on the proposed New Code of Practice (L.C.C., 1932). It is proposed that where both ends are properly fixed, the effective length of the column shall be considered as 0·7 of the actual length. The position of the curve has been purposely adjusted, so that the value of L (in the slenderness ratio $\frac{L}{R}$) is the actual length of the column and not the effective length.

Curve No. 2 is the American Institute of Steel Construction formula, with a maximum stress per square inch of 6·75 tons. The slenderness ratio is limited to 180.

Curve No. 3 is the Claxton Fidler formula (with $f = 26$ tons).

Curve No 4 is the Dorman Long formula.

Curve No. 5 is the Moncrieff formula for flat ends (as used by Redpath Brown).

The curves shown give various formulae plotted in graph form. For main members such as rafters if they are well restrained by the purlins and the struts, the stresses shown in Curve 5, Fig. 69 (the Moncrieff formula for flat ends), may be used for struts such as 1·2, 5·6. Stresses shown in curves 3 or 4 should not be exceeded. The end fixing will depend on the detailing, and it is important to note that a good design can, in a large measure, be spoiled by bad detailing. Detailing is important. There is a formula near enough for roof truss design which is easy to remember.

$$\text{Safe stress per sq. in.} = 7 - \frac{L}{30R}$$

To return to the design of B.1.

Length 104 in., least R of G 0·93 in.

$$\frac{L}{R} = \frac{84}{0{\cdot}93} = 90$$

From curve 5 safe stress = 5·7 tons/sq. in.

Area of two angles $3 \times 2\frac{1}{2} \times \frac{5}{16}$ is 3·24 sq. in.

$$\text{Actual stress} = \frac{11{\cdot}5}{3{\cdot}24} \text{ tons} = 3{\cdot}54 \text{ tons/sq. in.}$$

Allowable stress = 5·7 tons per sq. in.

Try two angles 3 in. $\times 2\frac{1}{2}$ in. $\times \frac{1}{4}$ in. Area 2·6 sq. in.

$$\text{Actual stress} = \frac{11{\cdot}5}{2{\cdot}6} = 4{\cdot}4 \text{ tons per sq. in.}$$

If curve 4 is used, safe stress = 4·7 tons per sq. in.

This will do nicely unless there is bending in the rafters due to purlins not being placed at panel points. If the purlins are not located over

the panel points (and this depends on what covering is used, whether sheets or secondary rafters and boards, or slates), then the rafter will have bending stresses as will direct compression and the angles should be increased to,

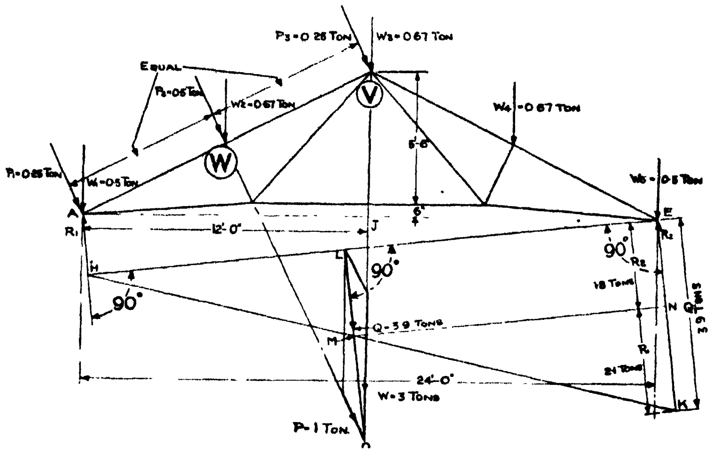


FIG. 70

say, $3\frac{1}{2}$ in. $\times$ 3 in. $\times$ $\frac{5}{16}$ in.

MAIN STRUTS (3.4 and 10.11).

Length 84 in.

Stress from table $2\frac{3}{4}$ tons.

In a strut like this two angles are generally used, but quite frequently only one angle of a somewhat larger size is put in. We will design both to show the method of applying the formula

$$7 = \frac{L}{30R}$$

Using only one angle. From the chart it will be seen that approximate R of G for one angle is ·2 of one leg for equal angles. Try one angle 3 in. $\times$ 3 in. $\times$ $\frac{5}{16}$ in.

Least R of G — ·2 in. $\times$ 3 in. = ·6 in.

$$\text{Safe stress per sq. in.} = 7 - \frac{84}{30 \times 6}$$

$$\text{,, \quad ,, \quad ,,} = 7 - \frac{84}{18}$$

$$\text{,, \quad ,, \quad ,,} = 7 - 4{\cdot}7 = 2{\cdot}3 \text{ tons.}$$

Area of angle is 1·78 sq. in.

Safe load 1·78 $\times$ 2·3 = 4·1 tons.

The load is eccentric because the fixing plate is riveted to one leg of the angle. This section would be suitable.

For the same member if we wish to use two angles.

Total stress is $2\frac{3}{4}$ tons.

Length 84 in.

Try two angles $2\frac{1}{2}$ in. $\times$ 2 in. $\times$ $\frac{1}{4}$ in.

Least radius of gyration

$$= {\cdot}31d = {\cdot}31 \times 2{\cdot}5$$
$$= {\cdot}77 \text{ in.}$$

$$\frac{L}{R} = \frac{84}{{\cdot}77} = 110$$

Safe stress from curve (4)

= 4 tons per sq. in.

Safe stress from formula

$$7 - \frac{L}{30R} \text{ tons per sq. in.}$$

$$7 - \frac{110}{30} = 7 - 3{\cdot}6$$

$$= 3{\cdot}4 \text{ tons per sq. in.}$$

Area of two angles $2\frac{1}{2}$ in. $\times$ 2 in. $\times$ $\frac{1}{4}$ in. is 2·1 sq. in. Actual stress will be $2\frac{3}{4}/2{\cdot}1$ = 1·4 tons per sq. in. It is not wise to have the slenderness ratio for this main strut more than about 140, and in practice this main strut would be made either one angle 3 in. $\times$ 3 in. $\times$ $\frac{5}{16}$ in. or two angles $2\frac{1}{2}$ in. $\times$ 2 in. $\times$ $\frac{1}{4}$ in.

By similar working it will be found that all the other compression members could be one

Wind Pressure at Right-angles to the Roof Truss = 56 per cent of Horizontal Wind Pressure.

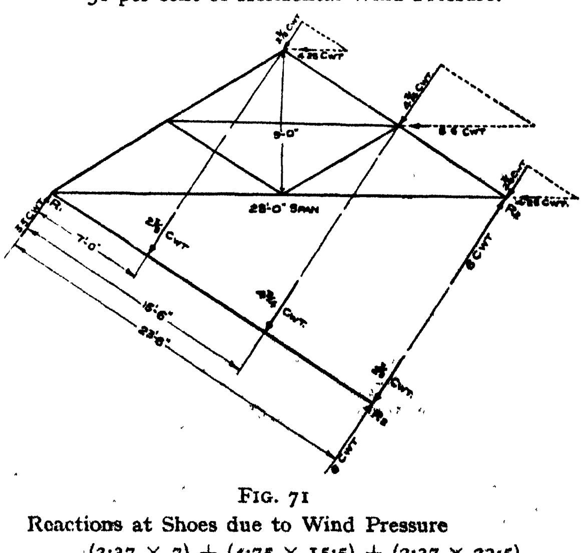


FIG. 71

Reactions at Shoes due to Wind Pressure

$$R_2 = \frac{(2{\cdot}37 \times 7) + (4{\cdot}75 \times 15{\cdot}5) + (2{\cdot}37 \times 23{\cdot}5)}{23{\cdot}5}$$

$$= \frac{16 + 74 + 55}{23{\cdot}5} = \frac{145}{23{\cdot}5} = 6 \text{ cwt.}$$

R_1 = Total Load — R_2 = 9·5 — 6 = 3·5 cwt.

angle $2\frac{1}{2}$ in. $\times$ 2 in. $\times$ $\frac{1}{4}$ in. All rafter angles will be two angles 3 in. $\times$ $2\frac{1}{2}$ in. $\times$ $\frac{5}{16}$ in.

MEMBERS IN TENSION. The bottom chord or lower tie as it is sometimes called, has a pulling stress of approximately 10 tons near the shoes. In tension members it is necessary to find the net areas because the rivet holes obviously weaken the bar. Generally the bottom chord is made of two angles (so that it is capable of acting as a stiff member to transmit load from the windward stanchion to the leeward stanchion), but for special light construction the tie is sometimes made of flat bars or a round bar.

We shall design for two angles.

Maximum = pull or tensile stress 10 tons.

In order to use the least number of sections in the roof truss as a whole, try two angles $2\frac{1}{2}$ in. $\times$ 2 in. $\times$ $\frac{1}{4}$ in.

Total area is 2·1 sq. in.; assuming we take out two rivet holes (one in each angle), area removed is 2 in. $\times$ $\frac{13}{16}$ in. $\times$ $\frac{1}{4}$ in., say 4 sq. in.

Net area = 2·1 — ·4 = 1·7 sq. in.

Allowing 7 tons per sq. in. we get

Safe load = 7 $\times$ 1·7 = say 12 tons.

The actual load is 10 tons maximum, so the lower chord can be of two angles $2\frac{1}{2}$ in. $\times$ 2 in. $\times$ $\frac{1}{4}$ in. for the whole length.

DETAILS AT JOINTS. Suitable details for three of the main joints are shown in Fig. 68, A, B, C. Money can be saved by making good on simple details or wasted by making complicated details.

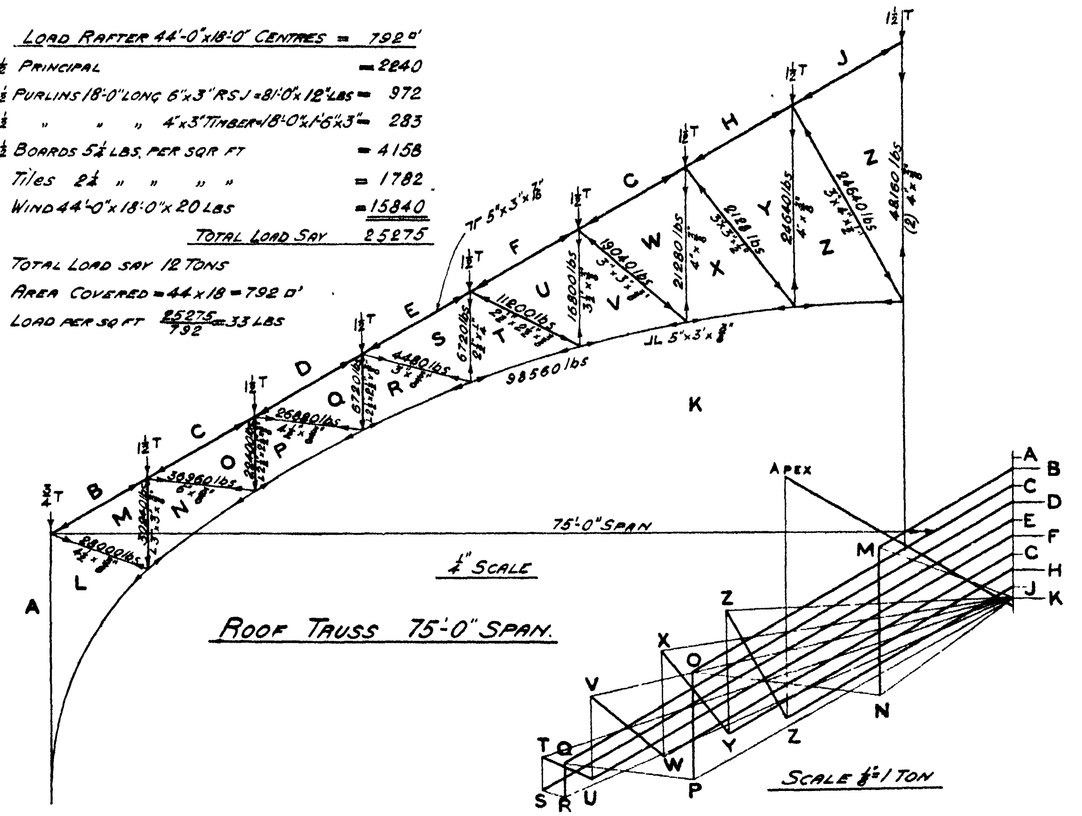


FIG. 72

Tabulation of Results. In tabulating the forces scaled from the diagrams, it is recommended that a + sign be placed against compression forces and a — sign against tensions. There should be one column for forces due to dead load, one for those due to wind load, and one for the maximum total force, either tension or compression. Some specifications allow working stresses for total load 25 per cent in excess of those for dead load only, so that if the wind load stress does not exceed 25 per cent of the dead load stress, it may be neglected. There should also be columns for the sectional areas of the members, the calculated stresses, and the required number of rivets at the ends.

Columns hinged at base

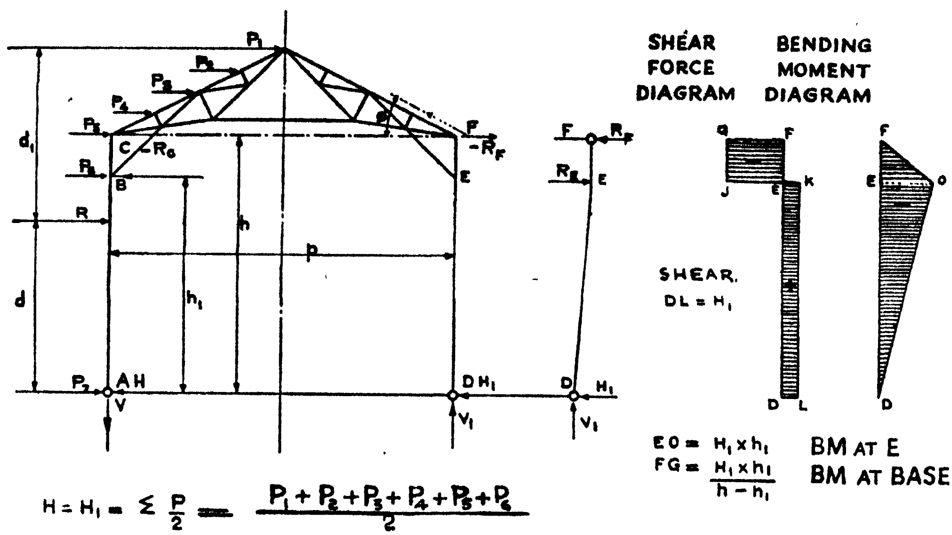


FIG. 72A

Columns fixed at base

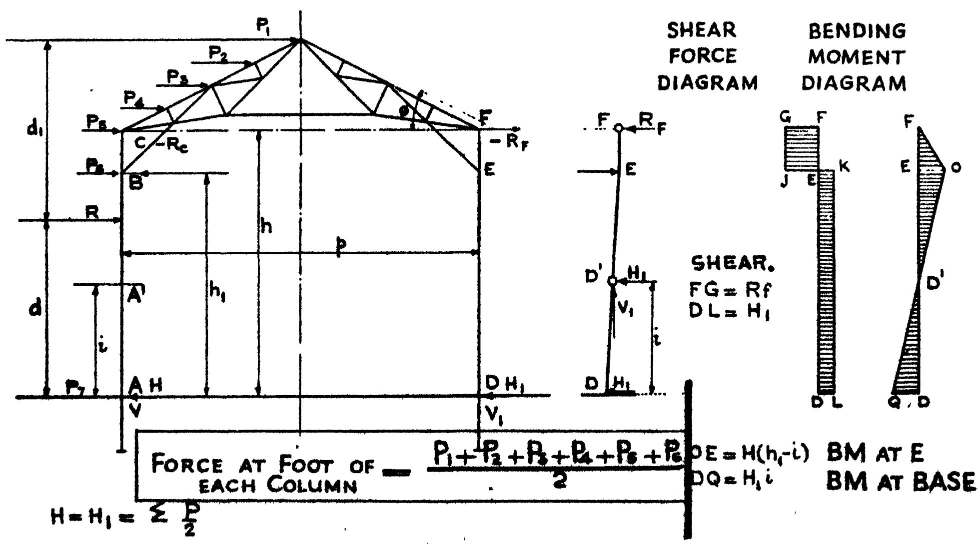


FIG. 72B

Angles in Tension. It is often specified that all members of a truss must be capable of resisting compression. When rolled steel angles are used as ties, as the force is usually transmitted through rivets in one leg, it is obvious that the whole section cannot be equally stressed; and to allow for bending stresses in the angle section due to eccentric loading, it is common to deduct half the area of the outstanding leg from the net tension area.

EXAMPLE. *Reactions at Roof Truss Shoes due to Wind Loads on Roof.* The truss is considered as a complete frame (see Fig. 70). In the example, notice that we have three wind loads on the left rafter; these are 0·25 tons, 0·5 tons and 0·25 tons, a total of 1 ton, and so far as the reactions or forces at the bearing ends (shoes) are concerned, it will make no difference if the whole wind load of 1 ton is assumed to act at the centre of the rafter (point *W*).

For the vertical (dead) loads, these are symmetrical or even about the centre of the span. We can add up all these vertical forces (three at 0·67 tons and two at 0·5 tons) and consider all these acting down vertically through apex *V*. We now have only two forces to consider so far as the reactions at the wall are concerned. These are the vertical loads of 3 tons and the wind load of 1 ton.

Proceed as follows. Drop a vertical line through apex *V* and extend the line through *W* representing the wind force at right angles to the roof. These two lines meet at point *O*. From *O* the two lines representing the vertical wind force of 3 tons, and the wind pressure of 1 ton. Then by the principle of the triangle of forces or parallelogram of forces find the resultant force *Q*. This is shown *LO* in the diagram. Through each of the supports draw a line parallel to this line *LO*. Through the point *L* draw another line *HLE* at right angles to *LO*. (It is just a chance that the line *HLE* happens to touch the shoe, it does not matter if it is above the shoe or below it. The point to be fixed is where line *HLE* cuts the line drawn parallel to line *LO*.)

Draw from *E* line *EK* of the same amount as *LO*; in this case it is 3·9 tons. Now join *H* to *K*, and note where this cuts line *LO* at *M*. From *M* draw a line parallel to *HLE* cutting line *EK* on *N*. Measure to scale the forces *NE* for the right-hand reaction R_2 (1·8 tons) and *NK* for left-hand reaction R_1 (2·1 tons).

Fig. 71 shows a form of roof truss often used in timber roof construction. In this case the wind forces are horizontal and by drawing to scale the resultant forces acting at right angles to the rafters are found. From the left-hand shoe a line is drawn parallel to the rafter against which the wind forces act. From the right-hand shoe draw a line at right angles to the rafter. Project the wind forces on to the line marked R_1, R_2. The distances shown on the diagram are found by scaling. The two reactions can now easily be found by using the principle of moments. The figures are shown in Fig. 71, and the reactions are shown to $R_1 = 3·5$ cwt. and $R_2 = 6$ cwt.

Now look at Fig. 72. This is a large span steel roof truss of the type used for theatres, drill halls, cinemas. Notice that the wind load in this case has been treated as a vertical force and that all loads are carried at joints where inclined web members are connected to the rafters. The total vertical load including the weight of the roof truss, purlins, covering, and wind pressure is 33 lb. per sq. ft. The total load and the load carried at each panel point is shown in the Fig. 72 after setting out the load line.

A, B, C, D, E, F, G, H, J, K, the stress diagram, can be drawn as shown. From this the stresses are scaled off, and a table prepared similar to the one for the 50 ft. span roof already designed (Fig. 68).

Suitable sections for the various members are shown (Fig. 72). The stresses in the various bars as obtained from the stress diagram are also shown.

Transverse Frames for Sheds. The framework for a steel shed is generally considered as a whole frame. The columns take bending stresses and shear forces, and the amount of these varies, both with the outside wind forces, and the condition of the fixing at the base of the columns. The two cases (for wind forces only) are shown in Figs. 72A and 72B. It will be noticed that the roof trusses in both cases have diagonal members between the columns and the roof trusses. These are known as knee braces.

Notice the bending moment and the shearing force at the foot of the knee brace is greater in Fig. 72A where the columns have round, hinged, or pin ends than in Fig. 72B, where the columns have fixed ends. Where the ends are fixed there is a bending moment and the foundations must be designed to take care of this. In designing the columns, there would be vertical loads, due to roof truss weight, roof covering materials, and purlins. The stresses due to these require to be combined with the stresses due to the horizontal wind pressure.

Chapter X—STEEL FRAME BUILDINGS

Floors. In the design of a steel frame structure it is first necessary to decide the type of floor to be used to carry the specified loadings. In times past it was usual to design for an inclusive load, which would cover for any type of floor construction in addition to a superimposed load usually far in excess of the actual, the specified total being expressed in hundredweights; but with increasing demands for economy it is now necessary to get a much closer approximation to dead and live loads, and make the dead load as light as possible, though questions of fire resistance and insurance costs usually rule out unprotected steelwork and wood floors.

Filler joist floors, discussed on page 1492, are in favour with many architects as they are simple to construct, the bottom shuttering can be suspended from the joists and they do not require such careful supervision as do many other types, but their dead weight is a disadvantage.

For relatively small spans, a thin reinforced-concrete slab is usually the most economical form of fire-resisting floor, but with longer spans the weight of a concrete slab may be excessive.

To reduce the weight, hollow terra-cotta tiles are often substituted for some of the concrete in the lower part of the slabs, leaving reinforced concrete ribs between the tiles—see pages 1489 to 1492 for examples of fire-resisting floors. Another type of floor offering many advantages is one in which the floor consists of a thin top slab supported by reinforced-concrete ribs forming a series of tee-beams; if necessary, an independent ceiling is suspended from the bottom of the ribs, after electric conduits, etc., have been installed between the ribs. Spans up to 30 ft. can be used with this type of floor.

Light precast members are sometimes used, which can be supported on the top flanges of steel joists, or if head-room does not permit this, on shelf angles riveted to the webs of the joists, or on suitably designed reinforced-concrete casing if the joists require to be encased.

As pointed out previously, the floor beams are designed as if simply supported at the ends, no account being taken of continuity. This undoubtedly results in high stresses in the end connections, and were it not for the ductility of steel, trouble would result.

Welded Joints. With the introduction of welding,[1] which makes possible junctions as strong as the members joined, this continuity will have to be taken into account, and methods of design similar to those employed in reinforced concrete will have to be employed, resulting in stiffer columns and shallower beams.

Though it is not proposed to discuss here the detail design of welded connections, it may be

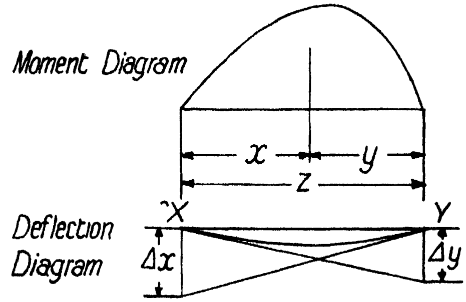


Fig. 73

helpful to indicate briefly a simple method of analysis invented by Professor Hardy Cross for the calculation of bending moments at the junction of structural members.

It is first necessary to consider how a beam of uniform section loaded in any manner deflects. Referring to Fig. 73, it has been shown previously that $E \cdot I \cdot \Delta x =$ the moment about X of the area of the bending moment diagram. If $A =$ this area and x and y are the distances of its centroid from X and Y respectively, then $E \cdot I \cdot \Delta x = A \cdot x$ and

$$E \cdot I \cdot \Delta y = A \cdot y \quad . \quad . \quad . \quad (58)$$

If hogging moments Bx and By are applied at the ends of an unloaded beam XY, the moment and deflection diagrams are as indicated in Fig. 74. The moment diagram can be divided into two triangles of area $\frac{Bx \cdot l}{2}$ and $\frac{By \cdot l}{2}$ respectively, the centroids of which are $\frac{l}{3}$ and $\frac{2l}{3}$ from X respectively.

[1] A useful chapter on this important subject will be found in Messrs. R. A Skelton & Co.'s Handbook No. 20A.

Therefore

$$E \cdot I \cdot \Delta x = \frac{1}{2} \cdot Bx \cdot l \cdot \frac{l}{3} + \frac{1}{2} \cdot By \cdot l \cdot \frac{2l}{3}$$

and

$$E \cdot I \cdot \Delta y = \frac{1}{2} \cdot Bx \cdot l \cdot \frac{2l}{3} + \frac{1}{2} \cdot By \cdot l \cdot \frac{l}{3} \quad . \quad (59)$$

If the hogging end moments of Fig. 74 are applied to the beam loaded as in Fig. 73, the resulting moment diagram is shown in Fig. 75, and the deflection diagram shows points of contraflexure where the bending moment is zero. The values of Δx and Δy will be the

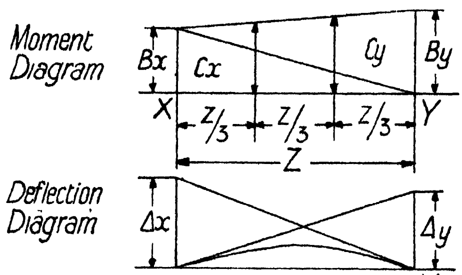


Fig. 74

difference of the values found for Fig. 74 and Fig. 73.

Thus,

$$E \cdot I \cdot \Delta x = Ax - \frac{l^2}{2}\left(\frac{1}{3} \cdot Bx + \frac{2}{3} \cdot By\right)$$

$$= Ax - \frac{l^2}{2} \cdot Cy$$

and $E \cdot I \cdot \Delta y = Ay - \frac{l^2}{2}\left(\frac{2}{3} \cdot Bx + \frac{1}{3} \cdot By\right)$

$$= Ay - \frac{l^2}{2} \cdot Cx \quad . \quad . \quad (60)$$

where Cx and Cy are the lengths shown at the third points of the span in Fig. 74.

If the ends of the beam are fixed and horizontal

$$\Delta x = \Delta y = O \text{ and } Ax = \frac{l^2}{2} \cdot Cy$$

and $\quad Ay = \frac{l^2}{2} \cdot Cx \quad . \quad . \quad . \quad . \quad . \quad (61)$

The last equation may be written

$$Cy = \frac{A}{l} \times \frac{x}{\frac{1}{2}l} \text{ and } Cx = \frac{A}{l} \times \frac{y}{\frac{1}{2}l} \quad . \quad (62)$$

$\frac{A}{l}$ is the *average* moment of the free bending moment diagram, and the values of Cx and Cy are readily obtained graphically as shown in Fig. 76.

The end moments in the case of a symmetrical load where $x = y = \frac{l}{2}$ equal $Cx = Cy =$ average moment.

If the end Y is freely supported,

$$By = O \text{ and } Bx = 1\tfrac{1}{2} \cdot Cx$$

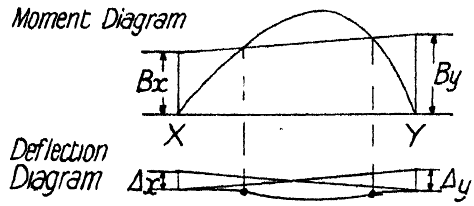


Fig. 75

If the end X is freely supported,

$$Bx = O \text{ and } By = 1\tfrac{1}{2} \cdot Cy$$

If the beam is unloaded,

$$Cx \text{ and } Cy = O$$

If X is fixed and horizontal, and a moment By is applied at Y, the diagram is as shown in Fig. 77, and $Bx = \frac{1}{2}By$.

If X is pin connected, the diagrams are as in Fig. 78.

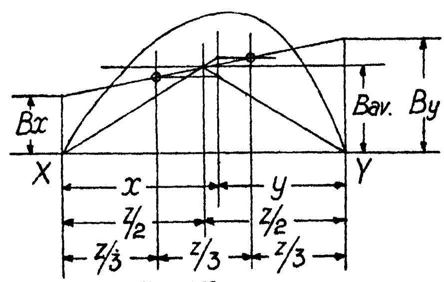


Fig. 76

If the slope at Y is the same in both Fig. 77 and Fig. 78, the values of $\frac{\Delta x}{l}$ are the same.

In Fig. 77,

$$E \cdot I \cdot \Delta x = By \times \frac{l_1}{2} \times \frac{2}{3} l_1$$

$$= \frac{By}{2} \times \frac{l_1}{2} \times \frac{l_1}{3}$$

therefore

$$E \cdot I \cdot \frac{\Delta x}{l_1} = By + \frac{l_1}{12} \cdot (4 - 1)$$

$$= By \cdot \frac{l_1}{4} \quad . \quad . \quad . \quad . \quad (63)$$

In Fig. 78,

$$E \cdot I \cdot \Delta x = By \times \frac{l_2}{2} \times \frac{2}{3} \cdot l_2 = By \frac{l^2}{3}$$

and $E \cdot I \cdot \frac{\Delta x}{l_2} = By \frac{l_2}{3}$ . . . (64)

For By in Fig. 77 to equal By in Fig. 78 and $\frac{\Delta x}{l_1}$ in Fig. 77 to equal $\frac{\Delta x}{l_2}$ in Fig. 78, the value of l_2 in Fig. 78 must be three-quarters of l_1 in Fig. 77. Thus a member XY fixed at X gives the

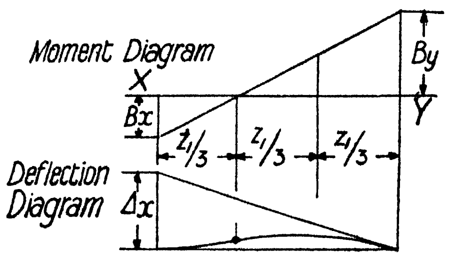


Fig. 77

same restraint at Y as a member of the same moment of inertia freely supported at X, if the length of the latter is three-quarters of the length of the former.

If two or more members OA, OB, OC, etc., having lengths la, lb, lc, etc., moments of

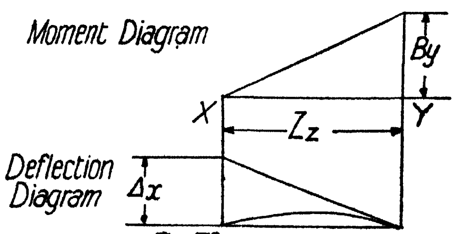


Fig. 78

inertia I_a, I_b, I_c, etc., are rigidly connected at O (Fig. 79), and the end O is rotated by a bending moment, each member will take its share of the bending moment B_a, B_b, B_c, etc.

The rotation of each member at O will be the same, i.e. $\frac{\Delta_a}{l_a} = \frac{\Delta_b}{l_b} = \frac{\Delta_c}{l_c}$, etc., and from equations 63 and 64. Bo for $OA = E \cdot \frac{I_a}{l_a} \times \frac{\Delta_a}{l_a} \times 4$ or 3, according as A is fixed or pin jointed. Similarly, Bo for $OB = E \cdot \frac{I_b}{l_b} \times \frac{\Delta_b}{l_b} \times 4$ or 3.

The moments in the various members at O are thus proportional to the stiffnesses defined by the ratio $\frac{I}{l}$, bearing in mind that the stiffness of a member with a pin connected at the far end is three-quarters the stiffness of a member not free to rotate at the far end.

In dealing with moments at a joint in a structure a sign convention must be adopted.

Moments tending to produce a clockwise rotation can be termed positive, and a counter clockwise rotation negative. Thus a hogging moment at the left-hand end of a beam is +,

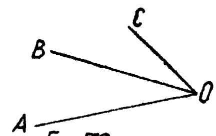


Fig. 79

and a hogging moment at the right-hand end is –.

The algebraic sum of the moments in the various members at any joint must be zero for the joint to be in equilibrium.

Consider a beam XYZ continuous over an intermediate support Y and freely supported at X and Y, neglecting the stiffness of the support at Y.

The moment diagram is shown in Fig. 80. If some external resistance fixes the beam at Y, the moments YP at the end of YX and YR at the end of YZ are the moments for loaded

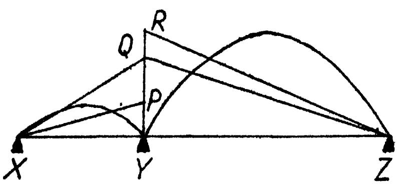


Fig. 80

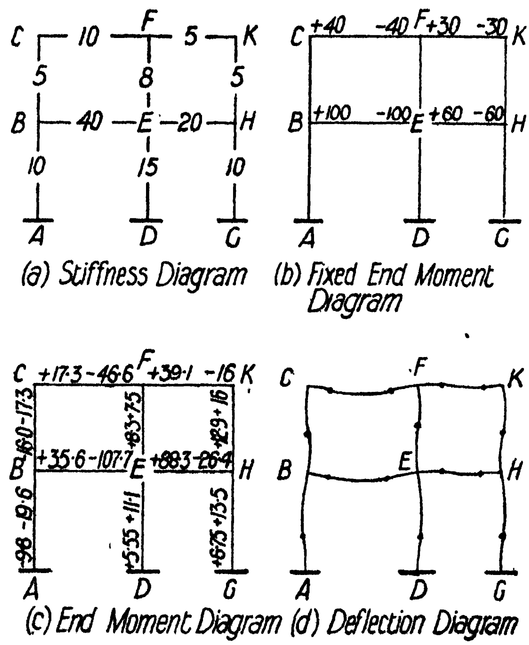
beams with one end fixed and horizontal. YP tends to produce counter clockwise rotation and is –, YR tends to produce clockwise rotation and is +, the difference PR is +. To establish equilibrium a balancing negative moment PR must be introduced. This balancing moment will be shared between YX and YZ in proportion to their stiffnesses, and the resulting moment at Y is YQ, where $QP : QR = \frac{Iyx}{lyx} : \frac{Iyz}{lyz}$

Consider a framed structure of which the relative stiffnesses of the members are shown in Fig. 81a, and the end moment of whose beams if the ends are fixed and horizontal is

shown in Fig. 81b. To analyse this the members are set out as in Table XVIII.

The end moments at A, D, and G, assuming that the bases are fixed, are half the moments $BA(-19{\cdot}6)$, $ED(+11{\cdot}1)$, and $HG(+13{\cdot}5)$, of which the algebraic sum is $+5$. There is thus a shear between the first floor and bases equalling $(5 + 2\frac{1}{2}) \div$ height AB.

For the frame to be in equilibrium, there must be a force acting from left to right equalling the above shear. This force keeping the column joints vertically in line is usually supplied by the floor acting as a stiff horizontal girder, transferring side reactions of the individual frames to the end walls, and the calculated moments are sufficiently accurate. If, however, the building is free to sway sideways it will move from right to left, reducing the positive moments



(a) Stiffness Diagram (b) Fixed End Moment Diagram

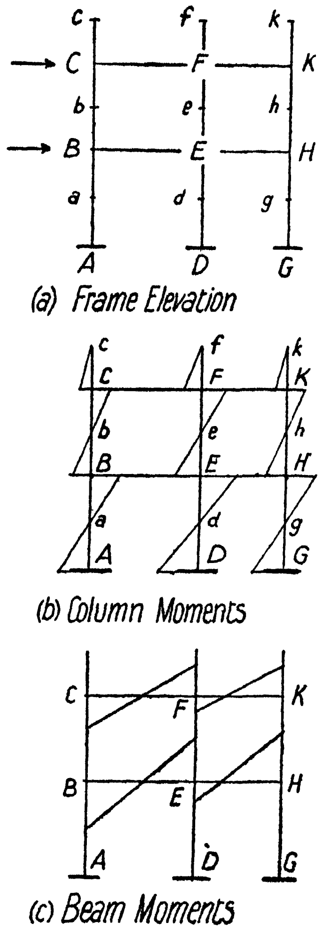
(c) End Moment Diagram (d) Deflection Diagram

Fig. 81

and reducing the negative moments till equilibrium is reached. The results of this side sway are sufficiently accurately estimated by assuming that there is a central point of contraflexure in each column, and that the shear is divided between the columns in proportion to their moments of inertia (and inversely proportional to the square of their heights if these are not the same, as may be possible, for instance, in the bottom storey of a building), which is a common method for the approximate analysis of wind stresses.

As stated previously, B.S.S. 449 requires calculation of stresses for wind pressure for only relatively tall buildings.

If the frame of Fig. 82a represents the bottom of a tall building, the whole of the horizontal



(a) Frame Elevation

(b) Column Moments

(c) Beam Moments

Fig. 82

load above C, B, and A is considered as acting on the lines cfk, beh, and adg respectively.

The bending moment of the loads at the floors above, for example, the line beh, produces tension in the windward columns BC and compression in the leeward columns HK.

If the centroid of the column areas is on the line XX, the moment of inertia of the three column areas is the sum of the products of their areas by the square of their distances from XX,

and the load in each equals $\frac{\text{bending moment}}{\text{moment of inertia}}$ × distance from XX, being a compressive load in the leeward columns to the right of XX.

If S_b is the share of the total shear above b taken by column BC the bending moment at the top and bottom of BC equals $Sb \times \frac{1}{2}BC$, and the bending moment diagram in the columns is as shown in Fig. 82b and in the beams is as shown in Fig. 82c.

The bending moment in the beam at C equals the sum of the bending moments in the columns at C but of opposite sign. The sum of the bending moments in the beams at F equals the sum of the bending moments in the column at F and these moments are divided in proportion to the stiffnesses of the two beams. The bending moment diagrams have been drawn on the tension side of the columns and girder.

To simplify calculations further, it is often assumed that the stiffness of the outside columns is half that of internal columns, and that the

TABLE XVIII

	Joint B				Joint C			Joint E				
Member	BA	BC	BE	Sum	CB	CF	Sum	ED	EB	EF	EH	Sum
Stiffness	10 ·182	5 ·091	40 ·727	55 1	5 $\frac{1}{3}$	10 $\frac{2}{3}$	15 1	15 ·181	40 ·482	8 ·096	20 ·241	83 1
[1] Fixed moments			+ 100	+ 100		+ 40	+ 40		− 100		+ 60	− 40
[2] Balance	− 18·2	− 9·1	− 72·7		− 13·3	− 26·7		+ 7·2	+ 19·4	+ 3·8	+ 9·6	
[3] Distribute		− 6·6	+ 9·7	+ 3·1	− 4·5	+ 2·1	− 2·4		− 36·3	+ 1·7	+ 17·1	− 17·5
Balance	− ·6	− ·3	− 2·2		+ ·8	+ 1·6		+ 3·2	+ 8·4	+ 1·7	+ 4·2	
Distribute		+ ·4	+ 4·2	+ 4·6	− ·1	+ ·8	+ ·7		− 1·1	+ ·7	− 3·5	− 3·9
Balance	− ·8	− ·4	− 3·4		− ·2	− ·5		+ ·7	+ 1·9	+ ·4	+ ·9	
Total	− 19·6	− 16·0	+ 35·6		− 17·3	+ 17·3		11·1	− 107·7	8·3	+ 88·3	

	Joint F				Joint H				Joint K		
Member	FE	FC	FK	Sum	HG	HE	HK	Sum	KH	KF	Sum
Stiffness	8 ·347	10 ·435	5 ·218	23 1	10 ·286	20 ·572	5 ·142	35 1	5 $\frac{1}{2}$	5 $\frac{1}{2}$	10 1
[1] Fixed moments		− 40	+ 30	− 10		− 60		− 60		− 30	− 30
[2] Balance	+ 3·5	+ 4·3	+ 2·2		+ 17·2	+ 34·3	+ 8·5		+ 15	+ 15	
[3] Distribute	+ 1·9	+ 13·3	+ 7·5	− 3·9		+ 4·8	+ 7·5	+ 12·3	+ 4·2	+ 1·1	+ 5·3
Balance	+ 1·4	+ 1·7	+ ·8		− 3·5	− 7·1	− 1·7		− 2·6	− 2·7	
Distribute	+ ·8	+ ·8	− 1·3	+ ·3		+ 2·1	− 1·3	+ ·8	− ·8	+ ·4	− ·4
Balance	− ·1	− ·1	− ·1		− ·2	− ·5	− ·1		+ ·2	+ ·2	
Total	+ 7·5	− 46·6	+ 39·1		+ 13·5	− 26·4	12·9		+ 16	− 16	

[1] The figures in the lower line are the proportional values of the stiffnesses of members at the various joints.

[2] These figures are the products of the unbalanced moments by the proportional stiffnesses but of opposite sign.

[3] A moment introduced at one end of a member produces a moment of the same sign but half the value at the other end, which is assumed fixed after every operation (see Fig. 77); thus the distributed moment in BE (9·7) is half the balancing moment introduced into EB (19·4). This process of distributing the effect of the moments at one end of a member by adding half that moment at the other end must be done after every balancing operation. The sum of the resulting moments must be balanced and the process continued till the unbalanced moments are negligible.

beams are of the same stiffness, so that the points of contraflexure in the beams from wind stresses are also central.

General Notes on Buildings. Just as there were failures in reinforced concrete construction in the early days (due to its being used in places where it was not suitable owing to excessive temperature changes, and also to lack of knowledge of its bad as well as good properties), so there have been cases where welding has not proved a complete success. Nevertheless, research and experiments have established the process and welded plate-girder construction, welded boilers, welded column bases, and splices are now very common. Welded roof trusses are also coming into the picture.

A part of a typical floor plan for a steel framed building is shown in Fig. 83. The columns and the beams are numbered for purposes of erection. Notice the two types of joint where the floor beams are fixed to the column. In one case beam 53 is fastened by a built-up bracket under the beam and a small angle on the top flange. In the other case there is a small angle (for erection) under the beam, but the load is carried by the $4 \times 4 \times \frac{1}{2}$ angles in the web of beam (53). For the small beam (166) the connection is the same in both cases.

There is much variation in the sections of the members and, accordingly, in the weights of roof trusses. Roughly speaking these can be divided into three classes—

1. *Light.* With flat bar tension members, very minor bracings, and often no gusset plates. Used for covering hayricks, open sheds.

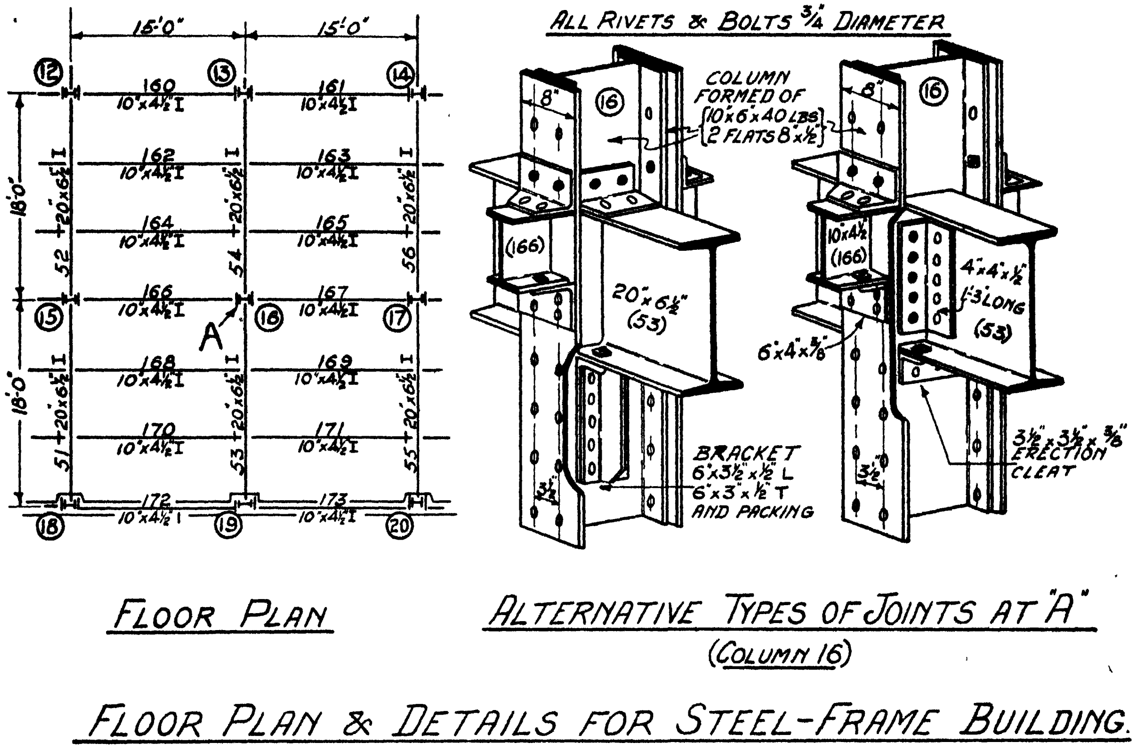


FIG. 83

2. *Medium.* This will be the general average type, with all members capable of taking compression and with adequate wind bracings.

3. *Heavy.* This may be due to bad chemical conditions, where acids make it desirable to keep members "thick enough," or where loads are to be carried from the roof trusses.

Industrial buildings (for cloth weaving, chemical, or metallurgical plants) are of two main types.

1. Single storey (sheds).
2. Multiple storeys.

Although single-storey buildings as a general rule (but not always) are more expensive than buildings with three or four floors, there are

many points to keep in mind before deciding against single-storey (shed) buildings. A heavy load can be carried on a ground floor with little vibration. With all the floor space at one level it is easy to change machines round if changed process of manufacture makes this desirable. The columns can be kept to a minimum with single-storey buildings, thus giving larger, free and clear floor space than with multi-storey buildings. Against these points, the multi-storey building has advantages in requiring less ground area, and reducing operating costs by using gravity flow from one level to a lower one. With a single-storey building it may be necessary (particularly in chemical and metallurgical plants) to put in costly elevators. Where the building houses heavy vibrating machinery, care should be taken to see that the loads are taken by foundations down to ground and that vibration is not transmitted to building columns.

Fire-Resisting Construction

By W. W. Dewar, A.M.I.Struct.E.

Chapter I—GENERAL PRINCIPLES AND STANDARD TESTING

Historical. Throughout the ages man has been confronted with the danger of fire in his buildings. With the growth in urban development and the demands for larger buildings as trade and industry grew, the problem of safeguarding life and property has continually increased. In Britain, prior to the Great Fire of London (1666), timber was the most widely used material for building construction, but, following that disaster, masonry came into further use, particularly for external walls and for walls separating buildings. This step undoubtedly provided a great measure of security against the risk of widespread conflagration when buildings were of relatively small size.

The extremely rapid growth of commerce and industry during the past century has brought with it the need for buildings having greatly increased floor area and height, a development which necessitated consideration being given to the protection from fire within individual buildings as well as for protection between separate buildings. Although fire-fighting measures have also developed greatly in efficiency to meet the increased risk, there is still a limit to the extent of fire which can be controlled by this means, and it has therefore become necessary to resort to internal structural measures of defence, i.e. construction which will resist the passage of fire and so limit the extent of fire which can occur within large buildings.

Much attention has therefore been given during the past fifty years in Britain, America and other countries to the development of fire-resisting construction, a study which has been intensified as a result of the experiences, on a large scale, of building fires brought about by incendiary action during war-time. This chapter attempts to summarize briefly modern conceptions and principles of fire-resisting construction, and to set down methods by which this type of construction is achieved in present-day building.

Fire Resistance, Incombustibility and Inflammability. In the past it was a popular conception that a material which did not burn was proof against fire, and therefore that buildings constructed of these materials could be regarded as "fireproof." Experience of fires taking place among the combustible contents of such buildings was quick to disprove this belief, and it came to be realized that no normal building material can remain entirely unaffected when exposed to fire. Iron and steel form, perhaps, the best example of such materials; although it is incombustible steelwork rapidly loses strength when exposed directly to fire, and most people are now familiar with the almost fantastic shapes into which it may be bent and twisted. The British Fire Prevention Committee, formed in 1895, carried out many practical tests and did much towards establishing a proper basis for the fuller understanding of the term "fire resistance," but its work was handicapped by the fact that there existed no standard by which tests could be placed on a truly comparative basis.

It was not until 1929 that a British Standards Institution Committee was formed with the object of clarifying the use of terms used to describe the properties of buildings and building materials with respect to fire, and to set up standards whereby materials and whole elements of structure, e.g. walls, floors, columns, etc., could be tested in order to determine their efficiency in this respect. The Committee decided on the following definitions, which largely form the basis of British Standard No. 476—1932.

"*Fire Resistance*—a relative term, to be applied to elements of structure only, and used to designate that property by virtue of which an element of structure as a whole functions satisfactorily for a specified period, while subjected to a prescribed heat influence and load." Special note should be taken that this definition

makes no reference to the material, but to the element of structure as a whole.

"*Incombustibility*—a term to be applied to materials only. An incombustible material is one which neither burns nor gives off inflammable vapour in sufficient quantity to ignite at a pilot flame when heated in the manner specified."

A simple laboratory test was specified for use in determining whether a material could be regarded as incombustible or not, for building purposes. The Committee also introduced the term "inflammability" in order that distinction might be made between combustible materials which burn with varying ease. Three grades were adopted, i.e. non-inflammable material, material of very low inflammability, and material of low inflammability; and a simple test was again specified for use in determining the degree of inflammability of any material.

Objects of Fire-resisting Construction. Fire may spread throughout buildings and to other buildings by various channels, which it will be well to enumerate, because they indicate the positions where resistance to fire is required.

Within a building fire may spread—

1. By failure of the floors separating storeys.
2. By failure of the walls separating one compartment from another. Failure in both cases may be brought about by the direct action of the fire on the walls or floor panels, or by the failure of the columns or beams which support them.
3. By direct communication through openings in the floors and walls, including staircases and lift shafts.
4. By communication from lower to upper openings in the external walls.
5. By smoke explosions which may follow the spread of smoke and gases from lower to upper floors.

Fire may spread from one building to another—

1. By failure of the walls separating buildings.
2. By radiant heat and flames issuing from openings in the external walls or from the roof, to openings in the walls or the roofs of other buildings.
3. Where combustible material is used externally, by the ignition of such material from radiant heat or hot gases and flames or flying brands issuing from another building or other external source of fire.

If, therefore, the walls and floors which surround the various parts of buildings, together with any structural supporting members, can endure the effects of fire from within or without, then theoretically the fire which may occur within one part of a building should not spread to other parts of the building or to other buildings. It must be emphasized, however, that the need for stair and lift shafts, doors, windows and other openings, makes the problem difficult in practice, and the most that can be done is to ensure that every reasonable precaution is taken to prevent spread of fire. It may therefore be said that fire-resisting construction is necessary in order to ensure, with reasonable certainty, first: that when a fire occurs within a building it will be confined to one part of the building only; and secondly, that no part of the building will take fire when it is exposed to fire externally.

It has already been stated that no building constructed of incombustible materials can be regarded as "fireproof." Fire may break out at any time among the combustible contents, with the result that the contents may be entirely lost and varying damage done to the building structure itself. The only way to prevent the incidence of fire within a building would then be to render the combustible contents immune from ignition—an entirely impracticable proposition, of course. However, the more precautions which are taken by the incorporation of fire-resisting construction and other methods, the nearer the building will approach the ideal, but at the same time the costlier will construction become. Latest conceptions of the problem aim to strike a balance between the cost of building and an adequate degree of protection against fire, taking into account the size and occupancy of the building, and also the part which the fire-fighting services can play in preventing spread. A building owner in deciding upon a desirable degree of protection for his building, will be influenced by such factors as the value of his stock and the chance of an outbreak of fire occurring, and the sizes of the various parts of the building may be affected accordingly; but there are limits of size which it is not advisable to exceed, because in the event of the failure of protective measures in a building of very large area, the fire services may not be able to control the large volume of fire which could occur.

Thus large buildings should, wherever possible, be divided up by fire-resisting construction into cells which are each capable of containing a fire within their own boundary walls or walls

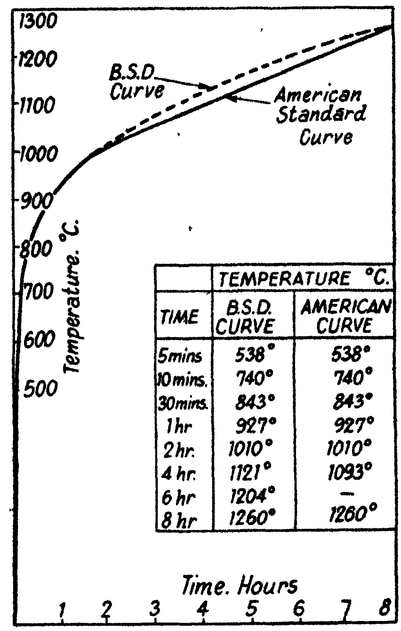
and floors. The various factors which may determine the sizes which can be tolerated for individual cells cannot be discussed in detail in this section, but it is generally conceded that a cubic capacity of 250,000 cub. ft. should not be exceeded unless special precautions, such as the installation of sprinkler systems and automatic fire alarms, are taken to reduce the chance of serious outbreak of fire to negligible proportions.

In deciding the degree of fire resistance required of the various elements of structure in a building, the intensity of the fire which may occur and be maintained is the controlling factor. Fire of great severity may occur, and will not be easy to control, if the area of the building is large; in order to meet such a case it is necessary that the elements of structure should be able to endure the full severity of the fire, i.e. complete burn-out within the part of the building involved.

At the other end of the scale, internal protection from fire may be regarded as unnecessary when the building is very small, for there will be little at stake, and it is often sufficient to rely on fire-fighting measures to control the fire and, in conjunction with party walls, to prevent spread of fire to other buildings. In between these extremes of size a gradation of fire resistance giving protection for limited periods only may be sufficient, having regard to the fact that the fire-fighting services, generally speaking, can control fire in small buildings within a much shorter period than is required in the case of larger buildings.

Little attention has been paid up to the present day in Britain to the problem of relating size of buildings and fire resistance. One important exception is the London County Council which exercises control, under the various London Building Acts, over the whole of the construction of buildings exceeding 250,000 cub. ft. in extent. In America in recent years, however, many codes which attempt to rationalize the relationship between the required degree of fire resistance and the size of buildings, according to the severity of fire which may be expected with the various classes of occupancy, have been legalized.

Fire Severity. The severity of fire which may occur within a building may be expressed in terms of the temperatures reached at various stages during the fire and the duration for which these intensities are maintained. A fire may attain a very high temperature but, if this intensity is maintained for a short period only, the total severity of the fire will not be great and little damage may ensue; relatively low temperatures continuing for long periods may cause greater damage to a structure. Fires of



TIME	TEMPERATURE °C. B.S.D. CURVE	AMERICAN CURVE
5 mins	538°	538°
10 mins.	740°	740°
30 mins.	843°	843°
1 hr	927°	927°
2 hr.	1010°	1010°
4 hr.	1121°	1093°
6 hr	1204°	—
8 hr	1260°	1260°

FIG. 1. TIME TEMPERATURE CURVE

great severity involve high temperatures that are maintained over considerable periods of time.

From a study of fused material remaining after fires in burnt-out buildings, combined with the knowledge of the temperatures reached during fires in some of the earlier testing furnaces, a standard time temperature curve was incorporated in a specification for testing the fire resistance of structural elements in America in 1918. The curve is shown in Fig. 1.

From data obtained from experimental fires[1] in test buildings containing varying quantities of combustible materials which were allowed to burn out completely under conditions of controlled ventilation, it was found possible to form a relationship between the severity of a fire, as indicated by one or more hours of the heating according to the time-temperature curve, and the maximum equivalent severity due to the combustion of a known weight of material of known calorific value.

[1] S. H. Ingberg. U.S. Bureau of Standards.

This relationship is shown in the following table—

Combustible Content		Equivalent Severity of Fire in Hours of Heating according to the Standard Time-temperature Curve
Weight Lb./sq. ft.	Calorific Value B.Th.U./sq. ft. of Floor Area	
10	80,000	1
20	160,000	2
30	240,000	3
40	320,000	4½
50	380,000	6
60	432,000	7½

In comparison with the actual severities of fire in buildings, where much heat loss occurs through windows, etc., and hose streams have some cooling effect, these values may be considered high. The conclusions, which may be drawn from consideration of the factors involved, indicate that the maximum equivalent severity to be expected from a burn-out would range from 1 hour in an office building where the combustible content would not exceed 10-12 lb./sq.ft. of floor area to 4 hours in a warehouse with combustible content up to say 50 or 60 lb./sq. ft.

The temperatures reached in building fires vary considerably according to the amount and nature of the combustible materials, and other factors such as the freedom with which the materials burn owing to their state of subdivision and the conditions of ventilation afforded; local areas of very high temperature may often be caused by forced draughts; but average temperatures usually vary from 600–800° C., with local maxima of 1,000° C. for office and residential buildings, to 1,000–1,200° C. (local maxima of 1,300° C.) in the case of large factories and warehouses, where fires of serious proportions occur.

Standard Test for Fire Resistance of Elements of Structure. The British Standard Definitions No. 476 for "Fire Resistance, Incombustibility, and Non-Inflammability of Building Materials and Structures," published in 1932, specify a test by which the fire resistance of elements of structure can be assessed, and it is thereby possible to ascertain the fire resistance of any element of structure by heating in specially constructed furnaces in accordance with a standard time-temperature curve. Elements may be placed in one of five grades according to the length of time they continue to function satisfactorily under test—

For Grade
A, elements must function satisfactorily for 6 hours
B ,, ,, ,, ,, ,, 4 ,,
C ,, ,, ,, ,, ,, 2 ,,
D ,, ,, ,, ,, ,, 1 ,,
E ,, ,, ,, ,, ,, ½ ,,

The standard time-temperature curve adopted is shown in Fig. 1, and is designed to represent the average temperature conditions of building fires. It is based on the evidence provided by temperature observations on fused metals after actual fires, and on the standard curves of the American, Swedish and German tests.

All test structures are required to be full size wherever possible, but, where the normal dimensions exceed 10 ft., representative portions may be taken, 10 ft. long in the case of columns, 10 ft. square for walls, and 12 ft. by 10 ft for floor panels which may include beams.

Test specimens are designed to simulate, as closely as possible, the conditions which pertain in normal use of elements in buildings; thus masonry partitions and concrete floor panels are generally restrained at all four edges, but load-bearing wall test panels and steel or reinforced concrete columns are free to move under expansion.

Load-bearing elements of structure are required to carry a load of one-and-a-half times the design load throughout the test, and to be capable of sustaining the same load when reapplied forty-eight hours later. Non-load-bearing elements of structure (except glazing) are subjected to an impact test in order to ensure that no unduly fragile structures are admitted.

Specimens tested for Grades A, B or C must pass a water test, which consists of the application of a water jet from a ¾-in. diameter nozzle at 20 ft. distance and 40 lb./sq. in. pressure for one minute for each hour exposure to heating.

Elements of structure are deemed to have failed unless they "remain rigid and do not collapse" throughout the test, and those elements which act as barriers to the spread of fire, e.g. walls, partitions, floors, etc., are required to fulfil the following additional conditions—

1. The average temperature on the unexposed face shall not increase at any time during the test by more than 139° C. above the initial temperature and shall not exceed 167° C. above the initial temperature at any point.

2. Cracks, fissures and other orifices through which flame can pass shall not develop.

Fire-resistance Test Building. Following publication of the Definitions, the Fire Offices' Committee erected, in 1935, a testing station at Elstree, and by arrangement between the Fire Offices' Committee and the Department of Scientific and Industrial Research, the Building Research Station has used the equipment for testing many of the traditional types of structure, and for special investigations of proprietary forms of fire-resisting construction.

FIG. 2. FIRE-RESISTANCE TEST BUILDING: WALL FURNACE

(Courtesy Fire Offices' Committee)

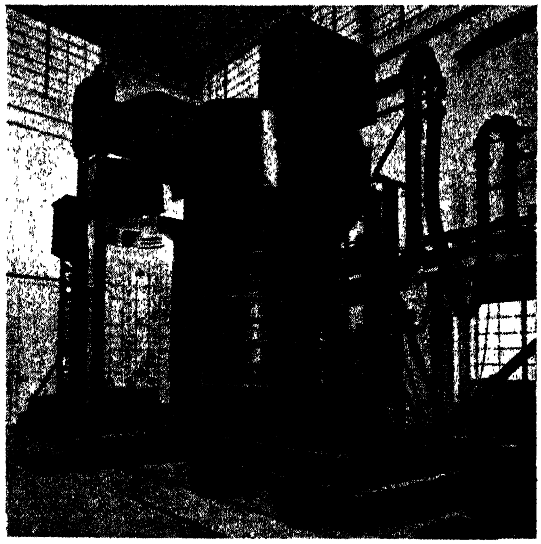


FIG. 3. FIRE-RESISTANCE TEST BUILDING: COLUMN FURNACE

(Courtesy Fire Offices' Committee)

The building is 138 ft. long by 37 ft. wide, and the height of the single storey is approximately 40 ft. An electric overhead gantry crane of 30 tons capacity serves the whole floor area.

Two bays at one end are set apart for the construction and conditioning of test structures. The remainder of the floor space is occupied by three specially designed gas-heated furnaces—the *floor* furnace, used for testing floor panels, beams and elements required to be tested in the horizontal position; the *wall* furnace (Fig. 2); and the *column* furnace (Fig. 3). The *floor* and *wall* furnaces are so designed that the test structures are subjected to heating on one surface only—the ceiling in the case of a floor, and either side in the case of a wall—while the *column* furnace is constructed in halves which, when brought together, completely encircle the test column. Temperatures within each furnace and on the test specimens are measured by means of a system of thermocouples connected to recording instruments in the control room, a small annexe overlooking the main building, and from which most of the operations in connection with the tests are controlled. Uniformity of heating in each furnace is maintained by regulating the gas/air supply, and very close adherence to the standard time-temperature curve can be obtained.

Loading is applied to floor structures simply by placing cast-iron weights uniformly distributed over the top surface to the total load specified. In the case of columns and load-bearing walls the specimens are placed in specially constructed compression machines, having a fixed top girder and a bottom girder moving between guides. Load up to 500 tons may be applied through the latter member by sets of rams operated by oil under a maximum pressure of 4,500 lb./sq. in.

In order to apply the water test to column and wall specimens while still under load, the wall furnace and each half of the column furnace are mounted on an electrically-driven undercarriage, so that the furnaces may be withdrawn completely from the test structures at the conclusion of the heating period. Loaded floor structures are removed from the floor furnace by means of the overhead crane and rest on four pillars while the water test is applied.

Chapter II—MATERIALS

General. Most of the materials used in building construction are incombustible. Timber is the important exception. Bricks and clay products, stone, concrete, steel and iron, plaster, etc., although they do not burn in themselves, nevertheless may be seriously affected by fire, and the effect of water on the heated material may also be considerable. Thus, although these materials are classed as incombustible, elements of structure constructed of them may suffer severe damage in the course of a fire; this damage may cause the structure to fail in its capacity as a fire resistant. Thus it must be emphasized that incombustibility of materials is no criterion of the fire resistance of an element of structure.

Although it would be an ideal attainment in some respects for structural elements to remain virtually undamaged after exposure to fire, leaving only superficial repair work to be done before the part of the building affected could be re-used, the adoption of such construction for buildings generally would result in a considerable increase in the initial cost of all buildings. As the incidence of serious outbreaks of fire is relatively small, the additional outlay involved would not be justified. Broadly speaking, therefore, it is in the interests of economy that fire-resisting construction need be capable only of fulfilling its purpose of preventing spread of fire, and it would be expected that much of that part of the construction which had borne the full severity of the fire would often require considerable repair, if not complete replacement.

Bricks and Burnt Clay Products. As may be expected from the mode of manufacture, bricks suffer no material change until very high temperatures are reached, and as the material is a poor conductor of heat, they therefore form one of the most satisfactory materials as regards resistance to the effects of fire. Spalling of the surface is often severe in some types of clay bricks, particularly of the harder and more dense engineering types. Softer and incidentally cheaper types of brick often show to better advantage than good quality bricks. Occasionally in very severe fires reaching temperatures of 1,200–1,300° C. the surface of brickwork melts. Sand-lime bricks are equally effective in their resistance to fire.

Hollow blocks of burnt clay behave variably when exposed to fire. Owing to the relatively thin shells of the blocks normally used expansion of the shell exposed to the fire sets up considerable stresses which cause it to fracture and spall off. This is more noticeable in the harder type of block than in the softer, more porous type.

Natural Stone. The natural stones, although bad conductors of heat, suffer appreciably from the effects of fire. Owing to the massiveness of normal stone construction, however, the effects are mostly of a superficial nature. Spalling of the surfaces, and especially the arrises, usually occurs even at relatively low temperatures, and no one kind of stone appears to be markedly better than any other in this respect. Cracking, often deep-seated and concealed, may occur, making the damage difficult to locate and repair, and fire-damaged stonework should always be regarded with suspicion. Much has been made of the calcination of limestones, but there is ample evidence to show that this is the least serious of the effects that occur. It is only at small depths from the surface that the temperature reaches the intensity required for the calcination to proceed at all quickly, greater damage occurring at greater depths due to cracking at lower temperatures.

Concretes. Concrete is a bad conductor of heat, and a valuable material for use in fire-resisting construction, although as may be expected from the composition and mode of manufacture of cement, it undergoes fundamental changes at relatively low temperatures. Little material change occurs to concrete heated up to 300° C., but between 300° and 600° C. physical and chemical changes occur which very considerably weaken the concrete. For practical purposes concrete which has become heated to 600° C. is useless structurally. The fact that it is a poor conductor of heat, however, prevents such high temperature being reached within the mass of normal structural units. Aggregates for concrete consist usually of quartz sand for the fine aggregate, while the coarse aggregate may consist of siliceous material (e.g. Thames

ballast), crushed limestones, Whinstones, sandstones and other crushed natural stones; in addition, crushed brick is commonly used and such light-weight aggregates as pumice and foamed slag. Concretes made with pumice, foamed slag, broken brick and limestone show to better advantage from the effects of fire and may be classed separately from the remainder. Concretes made from siliceous aggregates suffer most from fire, spalling of the surface occurring frequently in fires of no great severity.

Mild Steel and Cast Iron. Unprotected steelwork, although incombustible, is very vulnerable to fire. Steel is a good conductor of heat and has a coefficient of expansion of about ·000011 per degree Centigrade rise in temperature. When heated, the strength of the material is approximately the same at 400°C. as it is at normal air temperatures—the ultimate strength actually increases between these limits—but above 400°C. it decreases rapidly until, at about 600°C. the ultimate and yield strengths almost correspond and are only equal to the accepted working stresses. Furthermore steel which has been heated above 550°C. suffers a permanent small reduction of strength. It is not surprising therefore that unprotected steelwork in buildings, when exposed to fires of even light severity, fails in a very short period by collapse under load or by buckling due to the stresses set up by expansion, or by the combined effect of these forces. In addition expansion effects may tend to render walls and other parts of the structure unstable even though the steelwork is unaffected. It is therefore imperative to adopt some form of protection around steel framework in buildings of fire-resisting construction so that, in the event of fire, the metal is kept well below the critical temperature. Steel in plate or sheet form, when adequately fixed to framework, is effective in resisting the passage of flame, although the rate of heat transmission is relatively high, and it is widely used in the manufacture of fire-resisting doors and shutters.

Cast iron is seldom used for structural purposes in new buildings to-day, but in many existing buildings the internal structure is supported by cast iron columns, usually of hollow circular section. The strength of the metal is not affected so readily as mild steel, and unprotected columns may often remain virtually unaffected after exposure to fires of moderate severity. However, inherent weaknesses such as variation in thickness and texture due to the difficulties of casting, make cast iron an unreliable material for this purpose; failure under fire conditions of uneven heating and local cooling effects of hose streams, often occurs very suddenly by cracking followed by collapse.

Timber. Timber is a combustible material and, as such, it adds fuel to a burning building when used for part of the structure. Even so timber may attain a fairly high degree of fire resistance when used in heavy sections. The reason for this is that wood is a very bad conductor of heat and, following the initial charring of the surface, the conduction of heat into the depth of the timber is very slow, and time is required to build up sufficient heat to liberate the inflammable gases which form the actual flaming. The carbon remaining burns away very slowly by smouldering, and the deeper the burning progresses into the wood the slower the rate of penetration becomes. This property has been accorded full recognition in America and other countries where timber is in plentiful supply, and multi-storey factory buildings are commonly erected in "Heavy-timber Construction" which is rated as affording up to a 2 hour grade of fire resistance.

Hardwoods are generally accepted to be superior to soft-woods from the standpoint of fire resistance. Where fire-resisting doors of timber are allowed by building regulations, hardwoods only are specified for use. The British Fire Prevention Committee carried out a series of tests on doors composed of both hard and soft woods as long ago as 1899, when 1¾ in. thick doors of teak and oak resisted the effects of a furnace fire for approximately ¾ hour as compared with ½ hour for deal and pitch pine doors. It will be seen, however, that the latter attain a considerable degree of fire resistance, and a small addition to the thickness would advance their endurance to the standard of the hard wood doors.

Attempts have been made, chiefly by means of impregnation by solutions of ammonium phosphate and certain other chemicals under pressure, to render timber more resistant to fire. These treatments undoubtedly increase the resistance of timber to ignition, and in that respect obviously offer great advantages over ordinary timber from the standpoints of fire incidence and the spread of fire. (In some American Codes the material is classed together with unprotected steelwork in "Incombustible Construction.") Although there is very little data available at present, it is doubtful if any of the processes yet tried will affect to any

appreciable extent the ultimate endurance of elements of structure composed of the material when exposed to fire among the combustible contents of a building.

Timber is actually too inflammable to be classified under the standard test for inflammability, but it is, of course, commonly used, together with other readily combustible materials in sheet form, for lining the walls and ceilings of the compartments of buildings. Not only does the material add to the combustible content but, on account of the large surface area immediately exposed to fire, it permits a much more rapid build-up of fire and so may constitute a greater danger to both the buildings and the occupants. The considerable variation in the susceptibility to fire of the many kinds of combustible lining materials, led to the inclusion in B.S. 476, in 1945, of a test by means of which this type of material could be classified according to the ease with which flame may spread over the surfaces when exposed to varying degrees of radiation. This classification forms a basis whereby the use of combustible lining materials may be controlled.

Plaster. Plasters form a group of incombustible materials, which again are poor conductors of heat and valuable from the standpoint of fire protection.

Ordinary lime plaster is a relatively weak material, but, nevertheless, will resist the effects of quite severe fires if well keyed in position. Calcium hydroxide dehydrates into quicklime and water when heated to about 400° C. and contraction occurs.

This effect is observed on plastered surfaces by the cracking and crazing of the plaster. Rehydration of the quicklime on the application of water is accompanied by expansion with the consequent disintegration of the plaster.

However, as the plaster is a bad conductor of heat considerable time will be taken for the dehydration process to penetrate through the normal plaster thickness.

Lime-cement and Portland-cement plasters are much superior in mechanical strength to lime plaster, and considerably higher temperatures may be endured without causing serious physical change.

However, all types of plaster, when applied to solid surfaces having little or no key, readily loosen under the effect of strong heating and spall from the surfaces in large pieces at an early stage in a fire, the material itself being relatively unaffected.

They cannot therefore be relied upon to add materially to the fire resistance of structural elements to which they are applied, unless mechanically keyed, for example, by metal lath, or when a good key is provided on the surface as in some types of hollow clay blocks, and rough textured blocks such as clinker, foamed slag and pumice concrete blocks.

On the other hand when the side of wall or partition which is unexposed to the fire is plastered, the plaster will play its full part in delaying the rise of temperature on that side.

Gypsum plaster is used considerably in America in reinforced structural units, but in this country the material is chiefly used for partition blocks, plaster-boards and for plastering. Its interest from the fire standpoint lies mainly in its high combined water content which has a marked effect in retarding the conduction of heat. Dehydration begins at just over 100° C. with a resulting loss of strength, but complete dehydration is not attained until temperatures of 400°–500° C. are reached. This material is a good example of the value of combined and free water in building materials as an aid to fire resistance.

Asbestos Products. Asbestos is a fibrous natural mineral, incombustible and a poor conductor of heat. Its chief use for structural purposes is in the manufacture of sheet materials of ⅛ in. to ½ in. thickness.

Asbestos cement products are manufactured from cement and a low percentage of asbestos fibre, forming a hard, durable material much used for external and internal wall and roof coverings. On exposure to flame or moderate heat they generally crack, sometimes with explosive violence, and are therefore unsuitable to provide protection from fire. Asbestos-wood and wallboard, on the other hand, made with a much greater proportion of asbestos fibre, withstand strong heating well, and can be relied upon, when adequately fixed in position, to remain stable and afford a high degree of protection against the passage of flame.

Sprayed asbestos and moulded asbestos, both containing a high percentage of asbestos fibre, are highly resistant to the effect of fire and may be used for providing protection for steelwork, etc.

Slag Wool. Slag wool is a fibrous material made by the process of passing steam through the molten slag from blast furnaces. It is incombustible and again a poor conductor of heat. Made up into mattresses with wire netting it forms a cheap and reliable protection against fire.

Chapter III—FIRE RESISTANCE OF STRUCTURAL ELEMENTS

In the Model By-laws (Series IV) issued by the Ministry of Health in 1937, and in most other existing building regulations, it has been the practice to specify the materials and the thicknesses which would be accepted as satisfying the requirements for fire resistance, but such specifications are founded largely on experience and are therefore limited in scope. In 1938 the London County Council introduced regulations whereby application could be made for the modification or waiver of certain building by-laws so as to permit the use of fire protection for structural steelwork other than the protection required by the by-laws, provided that evidence was produced to show that the proposed protection was sufficient to enable the steelwork to endure the effects of the standard test fire for specified time periods determined in relation to the occupancy and size of the building.

This was a progressive step and it must again be emphasized that it is the actual performance of whole elements of structure, when tested under conditions simulating those of actual use, which count in respect of fire resistance; mere consideration of the individual materials of which the elements are constructed might be very misleading. On this footing the field is left clear for the use of any new materials and types of construction which may be evolved.

In the following pages reference is made chiefly to the more common types of construction used for walls, partitions, floors, steelwork protection, etc., employed in building to-day, but some other types are given which have been tested with respect to their fire resistance and serve to illustrate the principle mentioned above.

The indicated grades of fire resistance are based on the results of tests made at the Fire Testing Station at Elstree and on American data.

It is not part of the purpose of this section to enter into a detailed description of the construction of walls, floors, and other elements of structure, for which the reader should refer to the appropriate section, but certain details directly affecting fire resistance will be referred to when necessary. It should be clearly understood, however, that all the types of structure for which fire resistance gradings are given hereafter in this section, are assumed to be built up in accordance with accepted standards for good sound building practice.

Walls

The construction of the main load-bearing walls of buildings generally is controlled, largely on considerations of stability, by the various regulations in force throughout the country; in London by the requirements of the London Building Acts and By-laws, and generally in the provinces by the adoption of by-laws based on the Model Series issued by the Ministry of Health.

The materials which may be used include bricks or blocks of hard well-burned clay or terra-cotta, natural or cast stone, concrete, calcium silicate or similarly incombustible hard and durable materials (hollow bricks or blocks may be used if the volume of solid material is not less than half the total volume, and the width of solid material across the block is not less than one-third of the total width), mass concrete and reinforced concrete.

For load-bearing walls, solid brickwork of clay, concrete or sand-lime bricks laid in cement or cement-lime mortar is almost universally used, being the most generally satisfactory construction from the standpoint of utility, economy, and fire resistance. Hollow blocks are chiefly used for non-load-bearing walls of one or two storeys in height. Solid walls of stone are rarely built nowadays, except perhaps for monumental buildings. All stone containing quartz is liable to crack suddenly at relatively low fire temperatures, causing large pieces to become detached from the surface and arrises and fall, thereby constituting a danger to firemen. The face of walls of limestone may become badly disfigured even if the more dangerous and deeper seated cracking does not occur, and satisfactory repair work for either case is very difficult. Load-bearing stone walls, for these reasons, should be thicker than corresponding walls of brickwork. Stone-faced walls with brick backing are commonly used to-day, but no

reliance should be placed on the stone veneer to bear loading.

Tests have shown that the fire resistance of a 9-in. brick wall attains Grade A (6 hours), and as structural requirements demand a minimum thickness of 8½ in., the fire resistance of brick walls is satisfactory for all ordinary conditions of fire exposure. While the structural requirements laid down in terms of the heights and lengths of walls in relation to the thickness are also considered adequate from the standpoint of fire resistance, the fact remains that many walls of the load-bearing masonry type collapse during fires to the constant danger of firemen. These failures may often be attributed to the practice of building-in timber beams, plates, lintols, etc., which burn out during a fire and so cause considerable weakening of the walls, particularly those which already contain numerous window openings. The added buckling effects due to expansion under severe heating conditions often bring about collapse. Thus continuous timber plates should never be used unless special provision, with respect to fire resistance, has been made in the wall thickness to receive them, and the ends of timber beams should be splayed in order that as little damage as possible would be done to the wall if the floors collapse; metal wall ties should also be designed to this end (see Fig. 4).

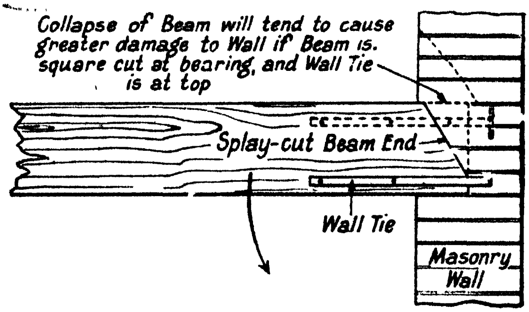


FIG. 4. WALL BEARINGS OF TIMBER BEAMS

Where the walls of a building consist of panels supported at each floor by a structural framework of steel or reinforced concrete, fire resistance becomes one of the controlling factors, and provided other conditions are satisfactory, e.g. weather-tightness and durability, various types and thicknesses of wall panels could be used, depending on the equivalent severity of fire which might occur within the building. Most of the tests involving suitable types of walling as an alternative to brickwork have been made in America on load-bearing panels, but the data may equally apply to non-load-bearing panels as failure is usually determined by the criterion of temperature rise on the unexposed face. Hollow concrete blocks, made with various aggregates, and hollow burnt clay blocks are chiefly used, either alone or in conjunction with a facing of brickwork. The degree of fire resistance of the blocks depends largely on the number of cells in the depth of the block and the thickness of the ribs; in the case of concrete blocks the type of aggregate plays an all-important part.

PARTITIONS

Partitions, apart from their primary purpose of separating areas of floor space where required, often serve as fire-stops within buildings and, especially in office buildings and flats where the fire severity is relatively light, may succeed in confining a fire to the room in which it starts.

A great variety of materials may be used, and the methods of construction include ordinary masonry work, timber-framing and light steel framing with outer linings of various materials. The thickness of partitions in relation to their height and length plays a most important part in the determination of their fire resistance as collapse is often the reason for failure especially with the thin masonry type. Test specimens are limited to 10 ft. square, but frequently the height and more often the length of partitions in buildings exceed this measurement. Consequently thin partitions constructed of bricks or blocks are often seen to collapse at an early stage in a building fire owing to expansion and bulging, particularly when rigidly fixed at all edges. No hard and fast rules can be laid down because the various materials of construction for partitions influence the performance under fire considerably, e.g. hollow clay tile partitions behave badly, as a rule, in comparison with partitions built of foamed slag blocks, but the following maximum heights and lengths relative to thickness may be taken as a guide for masonry partitions.

Thickness	Height	Length Between Supports
2 in.	8 ft.	16 ft.
3 in.	10 ft.	20 ft.
4 in.	12 ft.	24 ft.

Greater dimensions could be permitted if the partitions were reinforced in the horizontal joints.

Dimension of masonry partition

Stud partitions are usually fairly stable under fire conditions, and failure first occurs by flame or heat penetration. As in the case of wall panels, the degree of fire resistance offered by hollow block partitions will again depend on the number of cells within the depth of the block and the thickness of the ribs, and for solid and hollow concrete blocks, on the type of aggregate used. The conditions of test demand that elements of structure be tested under similar circumstances to their use in normal building work, and all non-load-bearing elements, including partitions, are therefore tested while fully restrained at all edges. Under these conditions severe stresses are set up by the expansion of certain materials when heated, with resultant bulging and, finally, collapse of the partition.

It is an essential requirement from the standpoint of economy that partitions should be light in weight, and it is fortunate that many of the lightweight concretes commonly used for partition slabs should also be excellent materials in respect of their behaviour when exposed to fire. Thus blocks of pumice and of foamed slag concrete are both light in weight and walls built with them are highly fire resistant, and their rough surface texture forms an excellent key for plaster. Pumice is an imported aggregate, but foamed slag, produced by controlled cooling, in limited supplies of water, of the molten slag from blast furnaces making pig iron, is now available in quantity in this country. Clinker and ordinary blast-furnace slag concretes are also good materials for fire resistance, although heavier than foamed slag. Coke-breeze concrete was widely used at one time, but is not regarded as satisfactory from the fire resistance standpoint owing to its high combustible content, and is not to be recommended. The term "breeze blocks" is often applied in error to blocks made of clinker concrete.

Wood-wool slabs also may form excellent fire-resisting light-weight partitions. They are made by mixing together cement and long strands of wood prepared from good sound timber, intertwined in a loosely compacted mass and finally pressed into slabs of required thickness and area. The open surface texture again forms a good key for plaster. Despite the combustible nature of the main ingredient of the material, the coating of cement over each individual strand of wood prevents the access of oxygen necessary for combustion, with the result that a process of charring takes place, but at a very slow rate of penetration through the depth of the slab.

Hollow and solid blocks made from gypsum plaster are light in weight and highly fire resistant, and finishing coats of gypsum plaster, of course, adhere firmly to the surface.

The British Standards Institution have published since 1933, Specifications Nos. 492, 728 and 834 for Solid and Hollow Pre-cast Concrete Partition Slabs and Pre-cast Concrete Blocks for Walls respectively. The specifications set down standard sizes, types of aggregate which may be used, and requirements for strength, etc., and, although only dealing with the technical requirements necessary for good practice, they should be followed and used as the basis for contracts.

The indicated grades given in Table I have reference to the fire resistance which may be expected from partitions constructed of blocks made in accordance with the specifications.

Framed partitions are not greatly in favour nowadays, block partitions being cheaper and generally more satisfactory, but a well-constructed framed partition, of timber or metal studding, can attain a good degree of fire resistance. The studs are usually covered with metal lathing on both sides, and plastered with cement and sand rendering with a finish coat of gypsum plaster, but other covering for the studs may be used including plaster boards, wood-wool slabs, etc., again with a finish coat of plaster.

By filling the cavity with an incombustible material of such good heat-resisting properties as slag wool or glass silk, the standard of fire resistance of partitions of this type may be increased by ½ hour or more. It is essential, however, that the filling should by made up in the form of mattresses, preferably bound with wire netting, which can be firmly fixed to the framework.

Floors

The main types of floor in general use for fire-resisting construction in this country to-day consist of a combination of concrete and steel in the following forms—

Steel joists with solid filling of concrete;

Solid reinforced concrete slabs;

Reinforced concrete slabs with hollow block fillers;

and the many proprietary types of hollow concrete floors embodying similar principles of design, but varying in details of construction, including: solid pre-cast units of I section,

TABLE I (*a*)

MASONRY AND OTHER SOLID WALLS AND PARTITIONS

Required thickness (in inches) of walls and partitions constructed of solid or hollow units for the period of fire resistance indicated

(When bricks or blocks are used standard thicknesses are adhered to)

Construction	Fire Resistance				
	6 hr.	4 hr.	2 hr.	1 hr.	½ hr.
Brickwork of clay, concrete or sand-lime bricks	8¾	8¾	8¾	4¼	4¼
Brickwork of clay, concrete or sand-lime bricks plastered	8¾	8¾	4¼	4¼	2⅝
Brickwork of cavity construction (2 in. cavity)	10½				
Brickwork of hollow clay bricks (70 per cent solid)	13¼	8¾	8¾	4¼	4¼
Brickwork of hollow clay bricks plastered	8¾	8¾	8¾	4¼	4¼
Half-brick facing bonded to 4 in. hollow clay-tile (50 per cent solid) backing, plastered		8¾			
Hollow clay blocks, plastered (50 per cent solid)—					
1 cell in wall thickness				4	3
2 cells in wall thickness			8		
3 or 4 cells in wall thickness		8			
Hollow concrete blocks, plastered (50 per cent solid)—					
Class 1 aggregates		8¾	4	3	2½
Class 2 aggregates				8¾	3
Solid concrete partition blocks, plastered—					
Class 1 aggregates		4	3	2	2
Class 2 aggregates			4	3	2
Reinforced concrete (0·2 per cent reinforcement), reinforced each way at 6 in. crs.—					
Class 1 aggregates	8	6	4	3	3
Class 2 aggregates	10	8	5	4	3
Gypsum blocks, plastered—					
Solid blocks			3	2	2
Hollow blocks (70 per cent solid)			3		
Wood-wool slabs, plastered			3	2	2
Cement plaster on metal lath and studs				3	2
Gypsum plaster on metal lath and studs				2½	2

Class 1 aggregates may include broken brick (unused), pumice, foamed slag, approved clinker and blast-furnace slag, crushed limestone.

Class 2 aggregates include flint gravel and crushed natural stone other than limestone.

TABLE I (*b*)

FRAMED WALLS AND PARTITIONS

Timber studs 2 in. × 4 in. nominal, or pressed steel studs, and lining material on both sides of studs

Period of Fire Resistance	Construction
½ hr.	⅝ in. lime plaster on wood lath and studding. ⅝ in. lime-cement or ½ in. gypsum plaster on metal lathing. ½ in. plasterboard. ½ in. gypsum plaster on ½ in. fibre board.
1 hr.	⅞ in. lime-cement or cement plaster or ¾ in. gypsum plaster on metal lathing. ⅝ in. gypsum plaster on ⅜ in. plasterboard. ½ in. neat gypsum on ½ in. plasterboard.
2 hr.	1 in. neat gypsum plaster on metal lath.

pre-cast units of hollow rectangular section, pre-cast units with hollow block fillers and *in situ* top concrete slab, hollow slabs of T-beam section with or without a suspended ceiling, etc.

A type of floor extensively used in America consists of small steel joists at approximately 3 ft. centres having a 2-in.–2½-in. top concrete slab poured *in situ* with reinforcement of expanded metal used as shuttering; the joists are protected from below by a ceiling of plaster or concrete on expanded metal, the thickness varying to suit the degree of fire resistance required. This type is light and economical where a thin ceiling protection only is needed, but the added dead weight of, say, a 1½-in. or 2-in. thick concrete ceiling results in a disproportionate increase in cost and an increase in total depth of slab, and a solid floor would be more satisfactory.

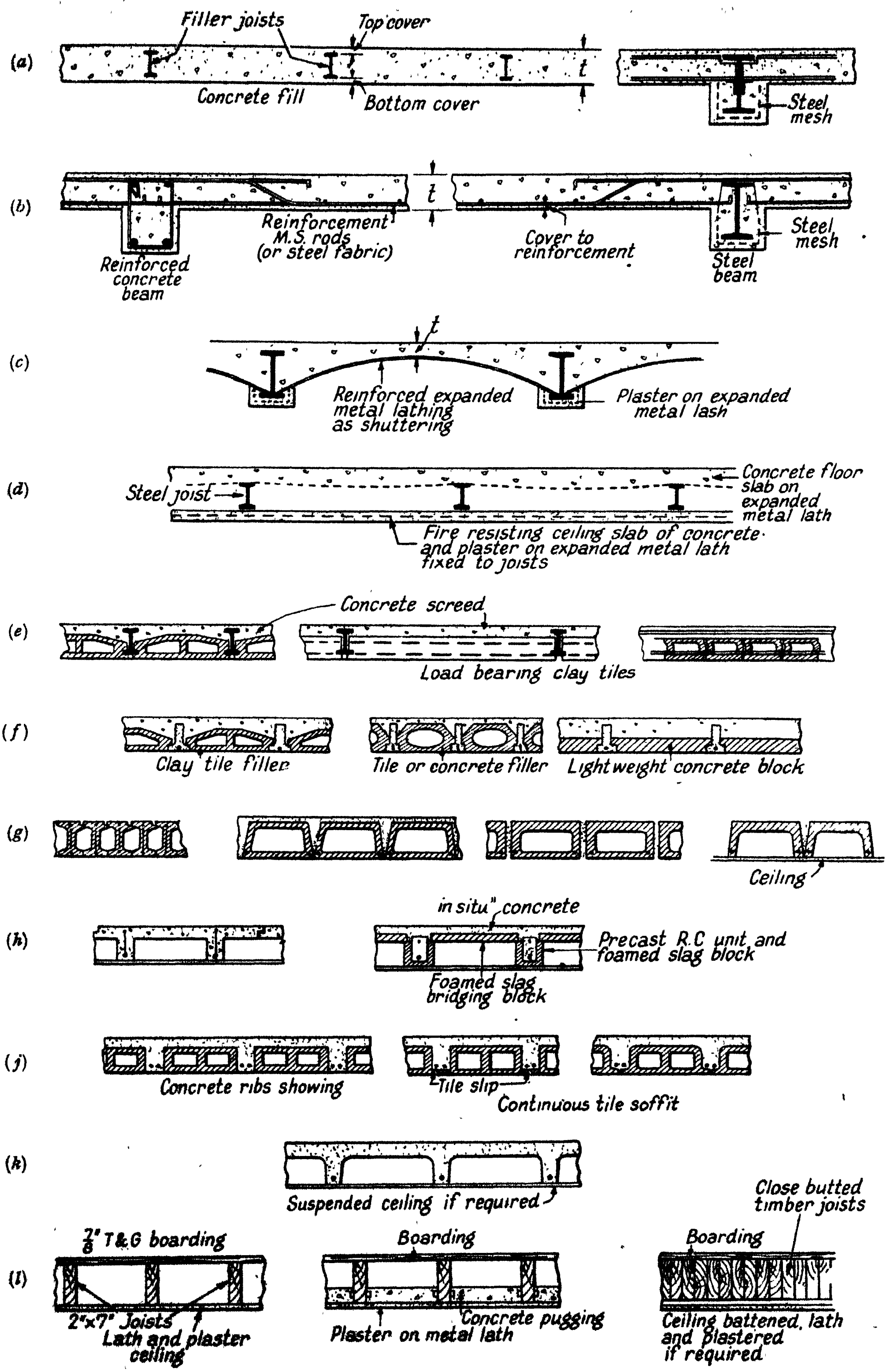


FIG. 5. FIRE-RESISTING FLOORS

Two types of floor, not in common use for new building work but which may be used in special circumstances and have a high degree of fire resistance, are worthy of mention.

The first type consists of brickwork arches spanning between steel beams, protected on the lower flange, and with a top filling of concrete levelled to cover the steel beams. Heavy superimposed loads may be supported but, although the standard of fire resistance is excellent even for the severest fires, the construction has the disadvantage of being too heavy for normal use, and where appearance matters, a suspended ceiling has to be provided.

The second type consists of timber joists of not less than 5 in. depth laid in contact with one another, spanning between heavy timber beams or walls, and finished on top with flooring boards. Such floors, although combustible, attain a high degree of resistance to fire for the reasons already mentioned under "Timber" in Chapter II. For light and moderate fire severities charring may penetrate to, say, 1 in. or 1½ in. depth, and the floor thickness should not be less than 5 in.–6 in., but for greater severities the joists should be at least 8 in. deep.

Generally it may be said that the fire resistance of floors constructed of concrete, clay blocks, etc., varies approximately in accordance with the thickness of solid incombustible material.

Filler joist floors may be used with the concrete filling composed of a variety of aggregates, and, especially where advantage is taken to use one of the better types of aggregate from the fire resistance standpoint, e.g. broken brick, a very high degree of fire resistance may be attained. Solid reinforced concrete floors are limited in the choice of aggregates on account of structural considerations, and the spalling which occurs with floors containing flint gravel or broken stone aggregates when tested in the furnace fully restrained on all sides, tends to reduce the period of fire endurance. The distribution of reinforcement in floor slabs also has material effect, and the greater endurance may be expected from a panel which is reinforced both ways by small diameter bars at close spacing.

The ordinary hollow-tile reinforced concrete floor in common use to-day combines strength with lightness and economy and a good degree of fire resistance. Although, during fires, the soffits of the tiles often split and fall away over large areas of the slabs, this type of floor is very satisfactory against moderate and light fire exposure. It is less efficient when the fire is severe because the relatively small section of the rib of the T-beam which becomes exposed on all sides after the tile soffit has fallen, often becomes very badly damaged, and the reinforcement heated well beyond the temperature which produces failure under load. Cases of failure by collapse of hollow-tile floors, as well as solid floors, seldom occur in fires mainly because the design superimposed load is rarely reached in practice.

Similar remarks apply to the many proprietary types of hollow reinforced concrete floors designed on the T-beam principle. No fire tests appear to have been made of these floors, and it is probable that considerable differences in degree of fire resistance would be obtained with the various types. Those types of hollow pre-cast units with thin shells and composed of flint gravel aggregate concrete, for example, are not likely to give good results, and plaster would not be expected to increase the fire resistance appreciably. On the other hand, floors which incorporate concrete units of foamed slag aggregate would be expected to have a much higher degree of fire resistance, and would have the further advantage that plaster would adhere to the soffit for a considerable time and thereby increase the period of endurance of the floor.

End spans of continuous reinforced concrete floor slabs, whether of the solid or hollow type, should always be well tied into the end supporting beams by top reinforcing bars in order to counteract the possibility of cracking of the slab at this point, followed by collapse.

Solid timber joist floors have already been mentioned as providing a good degree of fire resistance, but ordinary joist and boarded floors can attain at least the ½ hour grade by the use of a ceiling of plaster on metal lath, or the 1-hour grade if incombustible pugging is used between the joists. The latter method has been much used in the past, especially for providing a degree of fire resistance in existing timber-floored buildings, but the practice is not recommended for new construction.

Fig. 5 illustrates many of the types of floor construction in use in this country to-day.

Staircases

The construction of staircases is, of course, of paramount importance, both with regard to the safe exit of the occupants of buildings in

case of fire, and for the use of fire service personnel during a fire. Timber staircases may be considered adequate within small buildings of the domestic class, such as offices, flats and houses of not more than four storeys in height, but as a general rule incombustible construction should be adopted, and the amount of combustible trim used for handrails, balustrades, etc., should be reduced to a minimum. All staircases required for escape in buildings of fire-resisting construction, and in all other buildings of more than four storeys in height or which are occupied by a considerable number of people, should be enclosed by shaft walls of an appropriate grade of fire resistance. Where this is done it would not appear necessary for the stairs themselves to be highly resistant to fire, because they would be useless for their purpose if fire reached them before the occupants were able to escape; but in view of their importance to the safety of life and for fire-fighting purposes, stairs should preferably have a fire resistance against collapse equal to that required for the floors of the building, but not less than 1 hour, for even in lightly loaded buildings severe fire effects on the stairs may be obtained owing to the flue effect of the shaft. Staircases and landings of fire-resisting construction can readily be built in a similar manner to the floors of a building. The most usual types to be adopted are—

Solid or hollow tile reinforced concrete slabs, spanning between the main structural framework, the steps being cast monolithically with the slabs.

In situ or pre-cast reinforced concrete steps spanning between protected steel stringers or between newel and side walls. Natural stone steps should not be used owing to their tendency to crack and collapse when heated.

Pressed steel stairs with *in situ* concrete treads and soffit of plaster on metal lath.

TABLE II

FLOORS

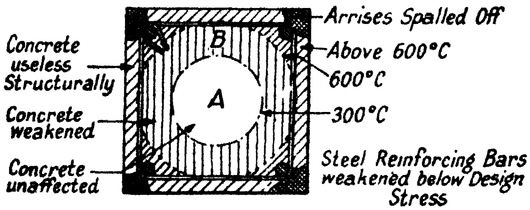
Thickness (in inches) of floor construction for the period of fire resistance indicated

Construction	Period of Fire Resistance				
	6 hr.	4 hr.	2 hr.	1 hr.	½ hr.
Solid Incombustible Floors.					
Filler joist and concrete floor panels (Fig 5*a*)—					
Reinforced concrete slabs, either flat slab or beam and slab construction (Fig. 5*b*)	7	6	5	4	3
(Concrete cover over top of filler joists should be at least 1 in. for 6 hr. to no cover for ½ hr.					
Cover to under-side of filler joists or to reinforcing bars should be at least 1½ in. for 6 hr. to ½ in. for ½ hr.					
Where Class 1 concretes are used the thicknesses may be reduced by 10–15 per cent.)					
Hollow Incombustible Floors.					
Hollow tile floors (Fig. 5*j*)—					
Minimum thickness of solid incombustible material .	6	5	4	3	2½
Proprietary types of hollow floor construction (Figs. 5*e*–5*h*) should conform to these thicknesses in order to attain the indicated periods of fire resistance.					
(Concrete cover to reinforcing bars should be at least 1½ in. for 6 hr. to ½ in. for ½ hr.)					
Steel joist construction (Fig. 5*d*)—					
Top concrete slab on metal lath		2½	2½	2	
Ceiling: Concrete (Class 1) or gypsum blocks . .		2½	1½	1	
Gypsum plaster on metal lath . . .			1	¾	

Wood Joist Floors (7 in. × 2 in. joists) (Fig. 5*l*).	Period of Fire Resistance
⅞ in. T. and G. boarding, wood lath and ⅞ in. plaster ceiling	½ hr.
⅞ in. P.E. boarding, metal lath and ⅞ in. plaster ceiling	½ hr.
⅞ in. T. and G. boarding, 2½ in. thick lightweight concrete pugging supported on timber fillets nailed to the joists and in centre of pugging, wood lath and plaster ceiling .	1 hr.

REINFORCED CONCRETE FRAMED CONSTRUCTION

Reinforced concrete framed construction offers in practice a high degree of resistance to fire. In the case of office buildings, flats and other occupancies where the amount of combustible material is low, this type of construction is rarely affected, as a result of fire, to a depth of more than an inch, i.e. any damage lies within the normal cover to the steel reinforcement; consequently there is little possibility of structural collapse and repair is a relatively simple procedure.



Load on heated column borne by full strength of concrete of area A, plus reserve of strength in weakened area B.

FIG. 6. HEAT PENETRATION OF REINFORCED CONCRETE COLUMN AFTER EXPOSURE TO SEVERE FIRE

In warehouses and the more heavily stocked parts of factories, where fires of much greater severity may occur, normal reinforced concrete framework is liable to suffer more serious damage. The fact that failure of the structural members is rare in the light of experience of ordinary building fires may be due to several reasons: buildings of this type are usually constructed of fire-resisting construction throughout; the fire is thus prevented from spreading beyond the compartment in which it occurs; the working stresses adopted are rarely reached in practice; fire-fighting apparatus is generally adequately provided in modern buildings, and the framed fire-resisting construction is a valuable aid to the work of the fireman.

If the protection of a *steel* framework is properly provided, no structural damage due to fire is likely to occur, although it is probable that the protective material will require extensive repair or in some cases complete replacement. Reinforced concrete construction is commonly thought to provide adequately its own protection, but, as already noted, concrete begins to lose strength when heated above 300° C., and becomes useless structurally when heated to about 600° C. In very severe fires the temperature may reach, say, 1,100° C. near the surface, and 300° C. at considerable depths into the concrete members, especially in the case of those members of small cross-sectional dimensions. The spalling characteristic of flint gravel aggregate concrete during moderate or severe fires tends to increase the depth of heat penetration. The steel reinforcement, generally within 1 in. to 1½ in. of the surface, may easily become heated beyond its critical temperature with respect to strength, and the whole load borne by the member, in the case of a column, is concentrated on the central part of the core which remains relatively unheated and therefore sound (see Fig. 6). It follows that if the load on the column happens to attain a considerable percentage of the design load, collapse is very likely to occur, and in any case the member may be so weakened that entire replacement is necessary, a procedure which is rather difficult and costly, in order to obtain a satisfactory repair.

It is, therefore, necessary to consider if some added protection of reinforced concrete framework is really needed in those cases where severe fire conditions can occur. The subject has received little consideration and it involves questions of fire risk and the cost of providing the extra protection. On balance, it would appear that, in view of the very few cases of actual failure of individual members of reinforced concrete framework, no added protection

TABLE III

Construction of Column	Test Load (= 1½ × design load)	Period of Endurance
	Tons	Hours
10 in. square; 0·8 per cent reinforcement . . . 1 : 2 : 4 mix ordinary grade concrete-flint-gravel aggregate. 1 in. cover to steel.	46	2
10 in. square; 5 per cent reinforcement . . . 1 : 2 : 4 mix high grade concrete-flint-gravel aggregate. 1½ in. cover to steel.	92	1
20 in. square; 1 per cent reinforcement . . . 1 : 2 : 4 mix ordinary grade concrete-flint-gravel aggregate. 1½ in. cover to steel.	200	3
20 in. square; 5 per cent reinforcement . . . 1 : 2 : 4 mix high grade concrete-flint-gravel aggregate. 1½ in. cover to steel.	367	2

need be provided except to columns and main girders of large trade and warehouse buildings, where collapse of one or two members might affect the safety of the whole building. It may be sufficient in such cases to provide a little extra cover and place light steel mesh reinforcement between the main bars and the concrete surface.

There are many factors which may influence the resistance of reinforced concrete structures with respect to fire, such as the kind of aggregate used, the strength grade of the concrete, the amount of reinforcement, etc., and it is apparent that there is scope for a great deal of research into the subject taking these factors into account.

Table III indicates the actual period of endurance, before collapse, of certain reinforced concrete columns tested in the standard furnace. It should be borne in mind that the test load is 50 per cent greater than the design load, a fact which has an important bearing on the period of endurance in the test.

Protection of Structural Steelwork. The disastrous effect of fire on unprotected load-bearing steelwork has already been pointed out in the chapter on "Materials." Protection of structural steelwork is required (*a*) to prevent the collapse of members under working load conditions, and (*b*) to prevent the distortion of the steelwork or damage to other members of the building structure through expansion of the steel.

Steel stanchions and main girders are the most important members to protect, as their collapse will affect the superstructure which they support. Beams are not so liable to fail by sudden collapse as stanchions as considerable

TABLE IV

STEEL COLUMNS AND BEAMS

Thickness (in inches) of protective covering to steelwork for the periods of fire resistance indicated

Protective Construction	Period of Fire Resistance				
	6 hr.	4 hr	2 hr	1 hr.	½ hr.
Solid Encasements (i.e. re-entrant spaces solidly filled with concrete or with the protective casing material)—					
Concrete (Class 1)	3½	2½	1½	1	1
Concrete (Class 2)	4	3	2	1	1
Gypsum concrete	3	2	1½	1	1
(Reinforcement for the above *in situ* protection should consist of wire mesh placed centrally in the concrete cover.)					
Brickwork, reinforced with steel wire in horizontal joints at approximately 12 in. intervals of height	4¼	3	2	2	
Concrete blocks (Class 1) and gypsum blocks, with wire reinforcement in horizontal joints	4	2½	2	2	
Sprayed asbestos			1	½	¼
Hollow Encasements.					
Brickwork (reinforced as above)		4¼	4¼	3	
Concrete blocks (Class 1) or gypsum concrete, reinforced in each horizontal joint	4	3	2	2	
Gypsum plaster on expanded metal lath				⅞	⅝
Cement or cement-lime plaster on metal lath				1	¾
Two layers (⅞ in.) gypsum, cement or cement-lime plaster on expanded metal lath with ¾ in space between			2½		

Additional Types of Encasement.	Probable Period of Fire Resistance
2-in. thick mattresses of slag wool in wire netting, wired around the member and plastered, re-entrant spaces also filled slag wool	4 hr.
Plaster-board ½ in. thick wired firmly to the steel and plastered with gypsum plaster ½ in. thick	1 hr.
Wood-wool slabs wired firmly to the steel and plastered—	
Slabs 2 in. thick	2 hr.
Slabs 1 in. thick	1 hr.

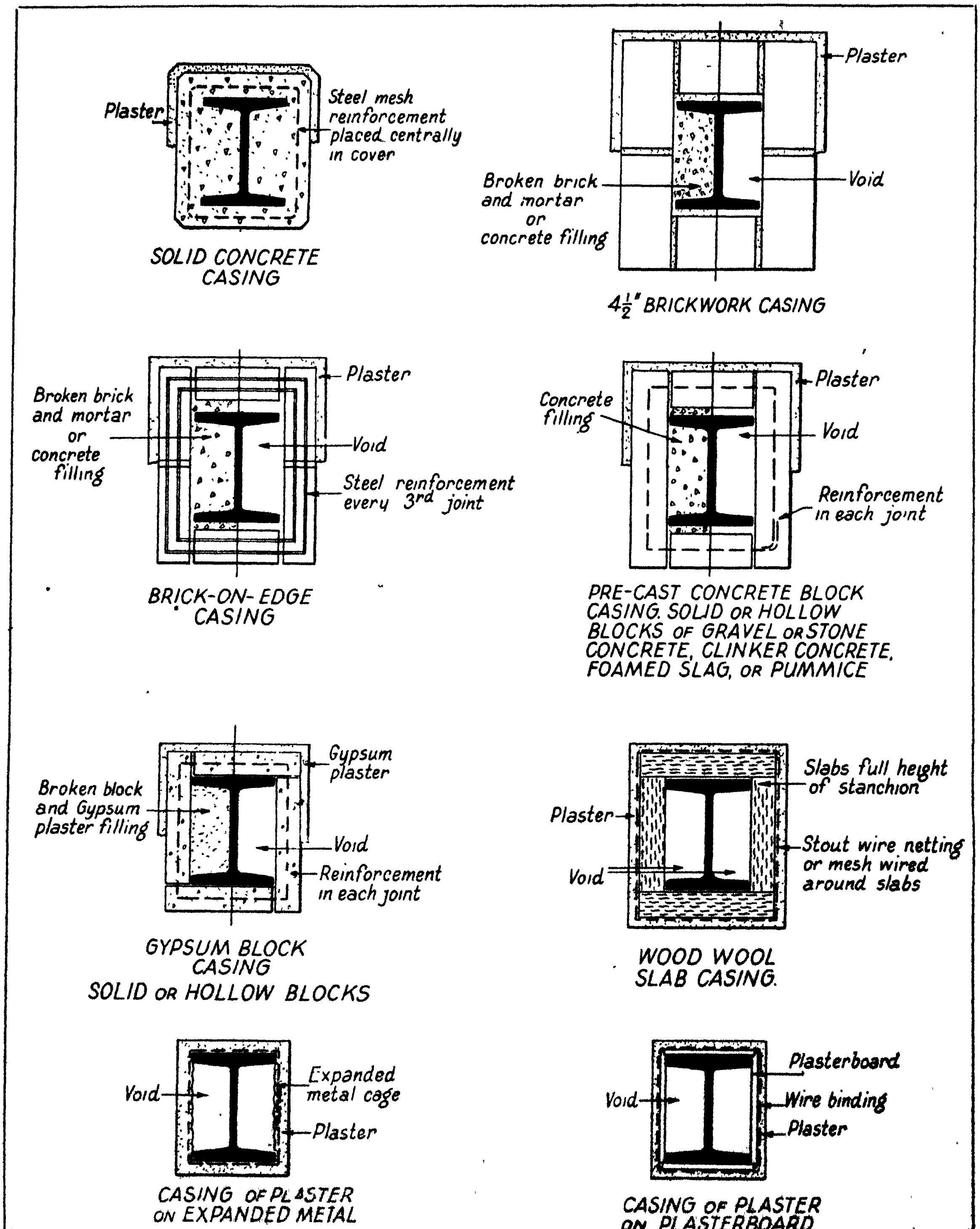


FIG. 7. PROTECTION FOR STEELWORK

deflection may be experienced before ultimate collapse occurs.

Many types of encasement may be used for the protection of steelwork, the choice depending upon a variety of factors, including the severity of fire against which protection is required, the cost of the protection and the availability of materials, the quality of surface finish, etc.

The most common forms of protection employed are casings of brickwork and concretes made with the local aggregate, although many other forms built-up of blocks of various materials including pumice and foamed slag concrete, hollow clay tile, wood-wool, gypsum plaster, etc., have been used. Solid casings of concrete cast *in situ*, although heavier than the latter types of protection are, on account of their solidity and strength, generally the most suitable form, especially for factory and warehouse buildings; additional advantages are economy of floor space and cost—projecting brackets, cover plates, etc., can be protected without the necessity of cutting bricks or blocks as in the case of built-up casings. The thickness of protective material required will depend on the grade of fire resistance applicable to the particular occupancy, and for office buildings, blocks of flats and other lightly loaded occupancies, where a finished surface is required, a protection of plaster on metal lath may be the best choice.

Concretes made from foamed slag, broken brick and limestone offer superior protection to those made with flint-gravel aggregates. Apart from the characteristic surface spalling of the latter, the considerable expansion experienced when strongly heated causes the casing which protects the flanges of steel stanchions to split away from the more solid web casing and fall, leaving the steel exposed. This necessitates the use of reinforcement if the concrete is to fulfil its purpose, and, while all concretes benefit from the use of some light reinforcement, a heavier quality mesh is essential with the flint aggregate concrete.

Brickwork 4½ in. thick will afford at least 4 hours protection to steelwork, but, where a lesser thickness may be allowed, reinforcement is necessary in the horizontal joints. The latter requirement is also applicable to all forms of built-up block protection. Where reinforcement is used in any form of protection for steelwork it is most important that it should be located in the middle of the protective material, and not bound tightly around the member.

Most of the forms of protection for stanchions will also be convenient for use with beams and girders, but generally the most suitable type for trade and warehouse buildings is the solid *in situ* concrete casing; metal lath and plaster may be used for office and residential buildings. When using metal lath it is important that the material should be attached to metal cradling fixed to the beams or stanchions, or even to stout wire bound round the framework. For cheapness timber grounds are often merely wedged between the flanges for fixing the metal lath; this is a practice to be avoided. Also, especially in the case of beams, heat can be conducted by the fixing nails and char the timber sufficiently to weaken the nail-hold, causing the whole protection to fall from the member.

Fig. 7 illustrates the more usual forms of protection adopted for ordinary framework of plain or plated rolled steel joist sections, together with some special types, and in Table IV the degree of fire resistance which may be expected with each type for varying thicknesses of cover material is indicated.

With the larger built-up girders it would usually be impracticable and very uneconomical to provide protection of solid casings, or in the case of lattice girders, by protection of the individual members. Fortunately these girders find most use in buildings where the severity of fire is not likely to be great, and it is usually possible to locate them, as for example balcony girders in cinemas, in voids surrounded by incombustible construction and protected from below by a suspended ceiling of plaster on metal lath.

Steel roof trusses are not, as a rule, required to be protected. Used chiefly on buildings of one or two storeys, this type of roof is cheap and permits of large uninterrupted floor areas. The additional dead-weight of fire protection would increase the cost out of proportion to the gain in fire safety. However, where a ceiling is necessary for other purposes, e.g. in cinemas and auditoria, a suspended ceiling of ⅝ in. plaster on metal lath will give good protection, especially where the storey height is large and the severity of fire thereby reduced.

Chapter IV—PROTECTION OF OPENINGS AND ROOFS

Openings

Internal Walls and Floors. Where walls and floors of an established fire resistance appropriate to the potential fire severity are used for the division or compartmenting of buildings, the hazard of spread of fire internally is largely eliminated; but horizontal and vertical communication is generally required between the compartments, which means that the internal walls and the floors must be pierced by doorways and vertical shafts. Protection for these openings must be provided of a standard equal to the fire resistance required of the wall or floor, but it should be realized that the most carefully designed protection can never be as effective as an imperforate wall or floor. Many serious fires involving the whole building have occurred through neglect to provide protection for one small vertical shaft passing through an otherwise adequate fire-resisting floor, and often the failure of inefficient protection has resulted in similar disaster. The first essential, therefore, is to reduce the number of openings in walls and floors to the minimum consistent with other requirements of the building, and then to protect the necessary openings by construction which should attain an equal grade of fire resistance to the walls and floors. The latter requirement would be difficult to achieve in practice owing to the temperature rise criterion of failure, but this criterion is waived under the British Standard Definitions for fire resistance, presumably on the grounds that where openings occur passageway is required, and thus combustible material will not be in the immediate vicinity, much less in contact with the doors or other protection provided. Thus the function of the protection is to prevent the passage of flame.

For the protection of door openings in internal walls, fire-resisting steel or iron doors, sometimes in combination with asbestos filling, and steel shutters are most commonly used. These may be used singly or in pairs, one on either side of the wall, according to the degree of fire resistance required. Doors may be of the hinged or sliding type; the shutters are designed to roll up into a hood attached above the door opening. Most types are made to act automatically by the use of a fusible link designed to release the door or shutter when fire occurs.

Space does not permit a detailed description of the various types of doors and shutters. It will suffice to say that they are usually designed and manufactured by specialist firms, and generally made and fixed to comply with the rules of the Fire Offices' Committee or, in London, of the London County Council. Approved single doors and shutters will provide at least 1 hour fire resistance, and double doors or shutters will offer 4 hours fire resistance.

Openings in the internal dividing walls of all trade and warehouse buildings should be protected by approved doors or shutters.

Solid timber doors not less than $1\frac{3}{4}$ in. thick are often used in situations where some measure of fire resistance is required. Tests carried out many years ago by the British Fire Prevention Committee indicate that such doors will give protection for over half an hour according to the standard furnace test, and while hardwood is commonly specified, good class softwoods are very nearly as efficient.

Staircase and lift shafts should always be protected by vertical enclosing walls preferably having a grade of fire resistance equal to that required for the walls and floors for large buildings, but some reduction could be made where the area of the building is small and the storeys few in number. Shaft walls are usually of small area, and certain of the thinner walls given in Table I will be adequate where the less severe fires may be expected, but for large warehouses and factories 9-in. brick walls or equivalent would be necessary. It should be borne in mind that walls around stairs and lifts in the latter classes of building are subject to rough usage, particularly around the openings, and thin walls are inadvisable even though the standard of fire resistance may appear adequate. Openings in the shaft walls should again be the minimum necessary, and protection should be provided by approved fire-resisting doors or shutters.

FIRE-STOPPING IN CONCEALED SPACES. Concealed spaces in building construction provide a means of rapid spread of fire throughout a

building and should be avoided whenever possible. The danger chiefly arises in connection with buildings having hollow-framed walls, partitions and floors, but other danger channels may be formed behind linings furred out from walls, in timber box cornices, in inaccessible enclosed roof spaces, etc. Fire-stopping is an inexpensive feature of construction and should be adopted freely wherever concealed spaces occur. The practice consists of blocking the cavities at appropriate points, preferably with incombustible material, but timber may also be used if the thickness is not less than 1½ in. to 2 in. (see Fig. 8). In this way a building of timber-framed construction may be rendered safer, for fire which may occur in one compartment is prevented by the fire-stops from spreading quickly to other parts, and the chances of controlling and extinguishing the fire before serious spread develops are much enhanced. Generally, it is most convenient to place fire-stopping at the junction of walls and partitions and at the junction of walls and floors, but in large compartments or in corridors and the like, the fire-stops should be spaced at intervals not exceeding, say, 25 ft.

External Walls. Many buildings, even when built of fire-resisting construction internally, have been set on fire because the window openings in an external wall were exposed to radiation, flames and flying brands from fire in an adjoining building. This external hazard may be of a very serious nature in that where the exposure is severe, several storeys of the exposed building may be ignited at once, thereby menacing the whole building—thus conflagrations develop unless fire-fighting services are adequate to control the danger.

It is, therefore, necessary to protect openings in the external walls whenever buildings are not sufficiently spaced to eliminate the exposure risk. The types of protection commonly used include: wired glass of ¼ in. thickness fixed in metal frames, folding and sliding doors and automatic rolling shutters, drencher systems, etc. The use of any particular type or combination of protection should depend on the correct assessment of the actual severity of potential exposure. The latter will be influenced by many factors, such as the size of the exposing building, its type of construction (whether fire resisting or not), the amount of window openings opposed to the other building, the severity of fire in the exposing building and the distance apart of the two buildings. Except in London, little consideration of protection from external exposure hazards appears to be made by local authorities, but in the interests of economy of insurance premiums, owners of buildings readily comply with the rules of the Fire Offices' Committee with regard to the protection of openings in

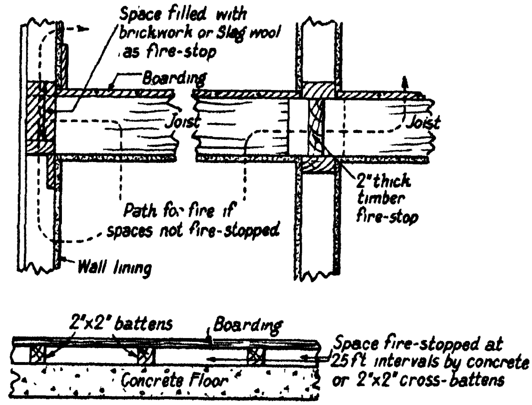
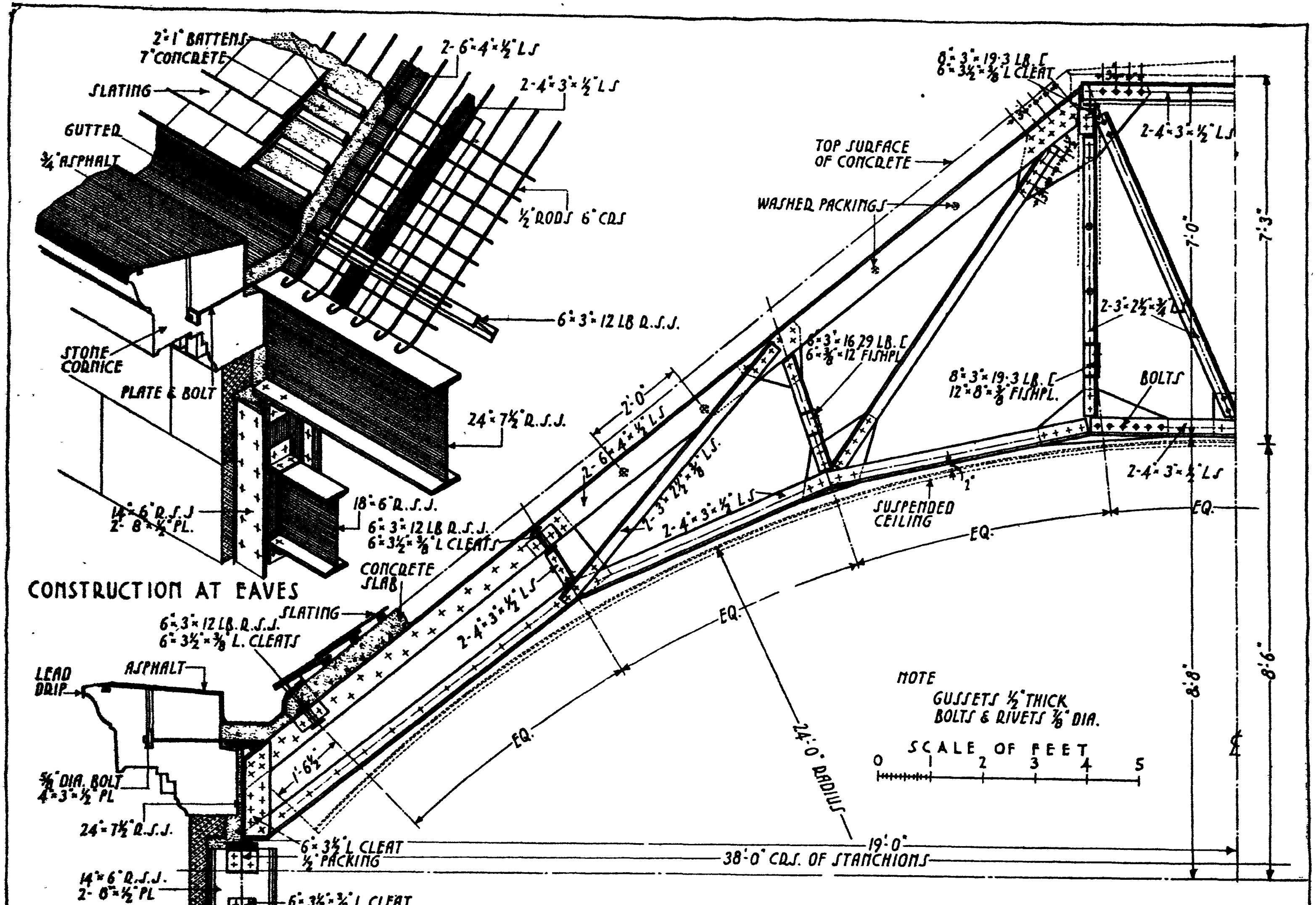


FIG. 8. FIRE-STOPPING IN CONCEALED SPACES

external walls. The correct type of protection required should, as stated above, depend on an accurate assessment of the exposure hazard, but until a satisfactory method is devised, the empirical rules of the Fire Offices' Committee, or in London, of the London County Council, broadly based on the distance between openings in opposing buildings, will decide. Wired glass in metal frames affords a most satisfactory protection, being cheap to install and maintain. The glass will, of course, allow the passage of some radiant heat, and will begin to soften and flow at a temperature of approximately 800° C.; it is, therefore, only suitable by itself for low and moderate severities of exposure.

Wired glass also forms an effective protection against the possible spread of fire from the window openings of one storey through those above Although there are objections on aesthetic grounds to the wholesale use of wired glass, such opposition can hardly be made in the case of warehouse buildings where the extreme severity of fire may result in spread of fire in this way where no protection is provided. Window protection offers a further advantage in that fresh supplies of air are largely excluded from the part of a building on fire until the fire services are prepared to ventilate that part. In this way a fire is often "damped" sufficiently to prevent rapid burning of the contents and spread of fire until control can be effected.

Where the severity is great, wired glass may



STEEL ROOF TRUSS FOR 38'0" SPAN

still be used in conjunction with a drencher system; the latter is designed as a series of pipes with special nozzles placed above the openings and with hand-operated valves, so that water may be turned on when required and allowed to flow over the outer face of the glazing, or form a water curtain over the opening, thereby keeping the glass cool and at the same time reducing radiation transmission and the effects of flame, hot gases and flying brands. Alternatively, various types of steel shutters may be used of which the automatic roll-up type is much to be preferred, but careful maintenance is required on account of exposure to weather.

The Fire Offices' Committee's rules also control the design of window protections, and although they are not, of course, mandatory, an inducement to follow them is provided by the reduction in insurance premiums which they earn.

Roofs

There are two aspects of roof construction to be considered with respect to fire resistance: (*a*) resistance to internal fire, which affects the actual structure and, to some extent, exposure to other buildings, and (*b*) resistance to external exposure from fire in other buildings, etc., which affects the covering material of the roof.

Roof Structure. The roof structure of buildings of fire-resisting construction should preferably be constructed similarly to the floors, i.e. should be of a grade of fire resistance appropriate to the potential fire severity of the upper storey of the building, although fire resistance is not usually considered so essential as for floors on the grounds that there is no storey above to take fire. Some opinions even favour a type of roof which will collapse early in a fire, and thereby provide ventilation for accumulations of smoke which hinder the work of firemen if allowed to remain in the building.

There is no doubt, however that very severe fire conditions usually follow collapse of the roof owing to the updraught which immediately results, and these conditions can prove a most serious menace to adjoining buildings, especially if the latter are higher than the building involved by fire. So from the standpoint of external spread of fire at least, all buildings, except perhaps those of quite small area, should have fire-resisting roofs unless well isolated from other property. Cost is a major factor influencing the type of roof construction, and the form which consists of steel trusses covered externally with weather-resisting material allows large unobstructed floor areas to be covered economically as well as reducing the load on the structure below. This type is of very little value for resisting the effects of fire from below, but in those occupancies where the amount of combustibles is small and the roof at a considerable height above the floor, e.g. cinemas and auditoria, the provision of a light ceiling of plaster on metal lath virtually assures full protection for the steel trusses. In such cases, however, the roof space should be kept as free of combustible material as possible, and any openings into the roof space, e.g. for ventilation, etc., should be protected with incombustible material. Owing to the great difficulty of fire-fighting in confined roof spaces and the rapidity with which fire can travel therein on account of induced draught, it is advisable to divide long roof spaces by fire partitions which may consist merely of plaster on metal lath or even corrugated iron sheeting.

When it is decided to adopt a fire-resisting roof construction, and most new buildings have that type of roof in built-up districts, it is usually most economical to use the same type of construction as for the floors, with a flat roof, but mansard roofs may be similarly constructed. Flat roofs also offer great advantages from the fire-fighting and escape standpoint.

External Roof Covering. Whether roofs are designed to resist the internal effects of fire or not, it is essential that they should not catch fire from external sources. For this purpose the roof coverings must be composed of materials which will resist sustained ignition themselves, and will prevent the ignition of any combustible parts of the roof structure by the action of flames, hot gases, radiation and brands. In addition, they should not produce flying brands when on fire themselves, and so endanger other buildings.

Roof coverings which are regarded as satisfactory and are commonly used, have been proved in the light of experience over very many years. The Model By-laws specify various materials for use as roof coverings (as set out below), and are applicable to all buildings except those domestic buildings which are not less than twice their own height from the nearest boundary or from another building, a restriction which virtually precludes the use of substandard coverings in urban areas. The use of other equally suitable materials is allowed,

but there is no definite standard by which such materials may be tested for acceptance, and it would appear that a means of testing which took into account varying degrees of severity of exposure would be of great advantage.

(*a*) Natural or asbestos cement slates.

(*b*) Burnt clay, concrete, stone, glass or asbestos-cement tiles or slabs.

(*c*) Lead, copper or zinc.

(*d*) Asphalt mastic, $\frac{3}{4}$ in. thick, laid on 1 in. boards, concrete or hollow tiles.

(*e*) Built-up bituminous felt sheeting (not less than three layers) on base of concrete or hollow tiles.

(*f*) Sheeting of asbestos-cement, wired glass, galvanized iron or steel (at least No. 24 B.W.G.) or protected metal.

(*g*) Bituminous material on a base of boards, concrete or hollow tiles, and covered with 1 in. thickness of concrete or similar material or $\frac{1}{2}$ in. bitumen macadam.

(*h*) Any approved slates, tiles, metal or sheeting or combination of materials (e.g. built-up coverings of asphalt-asbestos felt are generally accepted when applied to combustible roofs).

Sprinklers. Automatic sprinkler installations, although not strictly to be regarded as part of the construction, constitute such an important factor in the fire safety of buildings, that these brief articles would be incomplete without reference to them.

Development of sprinklers has been proceeding since about 1850. Modern installations comprise a system of pierced water-pipes, fixed generally below the ceiling level throughout a building, and so arranged that there is one outlet to each 80–100 sq. ft. of floor area. To each orifice, usually $\frac{1}{2}$ in. in diameter, is attached a sprinkler head, a device in which the water flow is withheld by an arm of soft alloy with melting point of about 150°F. When released by melting of the metal, water impinges on a cap of special design and is scattered in the form of a heavy spray over the floor area covered. At the same time a fire alarm is automatically operated.

Sprinklers are intended essentially to control and to give warning of fires in their incipiency, and normally one or two heads only are opened when fire occurs. For their successful operation sprinklers depend on an adequate water supply and pressure—5 lb./sq. in. minimum—and if spread of fire is so rapid that many heads are opened, the flow of water from each orifice will be reduced and the fire may not be put out. However records indicate that, in at least 75 per cent of cases, sprinklers are entirely successful and, of the remainder, in all but 2 or 3 per cent the fires are controlled sufficiently to prevent serious spread until the fire services arrive.

Sprinklers, approved by the Fire Offices' Committee, earn so large a reduction in insurance premiums that the cost of installation is generally a matter of long-term economy, quite apart from the security provided. Strict maintenance is very necessary, but the cost is low.

Concrete: Plain and Reinforced

By G. P. MANNING, M.ENG., M.INST.C.E.
Author of "Reinforced Concrete Design," "Construction in Reinforced Concrete," and "Reinforced Concrete Arch Design"

Chapter I—MATERIALS

Definition of "Concrete." A concrete consists of a large number of small inert pieces (called the *aggregate*) which are enclosed and joined together by an active medium (called the *matrix*, or *cement*) into one large solid mass (see Fig. 1).

The idea of a concrete was first evolved in connection with massive masonry work, the object being to form one large block of stone out of a number of small stones. Several of the earliest masonry structures are composed of what we to-day should describe as mass concrete. Although the earth's crust contains a vast amount of hard rock, it is an extremely difficult and expensive process to quarry large blocks and handle and transport them. It is cheaper to quarry the stone roughly, crush it, transport it, and then cement it together on the site; or, better still, use local sand and ballast beds, where possible, to provide the stony aggregate.

AGGREGATES

An aggregate must be strong, weather-resisting, of a suitable size, and possessing a surface to which the cementing material will adhere. In addition, and most importantly, it must be cheap. Natural sand and ballast, or broken stone, or brick are the only substances which fulfil these conditions, and their use as aggregates is universal. For convenience in gauging, it is usual to divide the aggregate into two classes—*coarse aggregate* and *fine aggregate*, the latter usually referred to as "sand." The two classes may not actually be divided one from the other in practice. For example, most beds of ballast consist of a mixture of the two. In such a case, however, it would suffice if samples were taken and tested to find out what proportion of sand were present. If necessary, the natural ballast could then be diluted by adding coarse aggregate alone or by adding fine sand alone, to produce a correct proportion of coarse and fine particles. In order to make certain that the cement will adhere to the surface, the aggregate must be *clean*.

Coarse Aggregate. When any concrete work is to be carried out, the cheapest coarse aggregate which will give good results is chosen. First, nearness to the site of operations must be considered. Transporting aggregate by rail or by road very soon doubles the price. It is, therefore, essential to use something *local*. The best aggregate in common use is crushed granite, but this, of course, has to be quarried and crushed and is usually not the cheapest. It is, therefore, only used when a hard-wearing concrete is essential. Natural beds of ballast worked by shallow, open pits offer a cheaper material which is second only to granite for strength and density. Broken limestone or sandstone may be used, their qualities varying according to the particular beds which occur in the neighbourhood. The value of broken brick as an aggregate depends on the type of brick. The cheaper kinds of building bricks

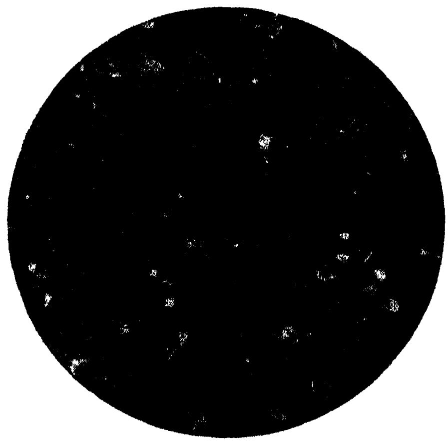


FIG. 1. STRUCTURE OF CONCRETE
Reproduced photograph of surface after grinding and polishing, showing structure (from a specimen prepared by Mr. R. H. H. Stanger, A.M.Inst.C.E.)

are both weak and porous, and a weak and porous concrete will result if they are used. Broken engineering bricks of good quality, or broken firebrick, make good coarse aggregate if available on the site in sufficient quantity. Cinders or clinker breeze will make a weak and porous concrete, but they are sometimes used, as the resulting concrete is lighter in weight than concretes made of other aggregates, and possesses the useful property that nails can be driven into it. The use of cinders, broken furnace slag, etc., is only possible if the sulphur-content is very low, as sulphur forms sulphuric acid, or acid sulphates, that interfere with the proper setting of the cement and, in the case of reinforced concrete, attack the steel reinforcing bars.

The first step, therefore, is to scour the countryside in the neighbourhood of the proposed new works, and get estimates for supplying coarse aggregate from all possible sources, with samples from each source. (In the case of large and important works, the possibility of opening up a quarry or gravel pit, specially to supply the job in question, must not be overlooked.)

The samples must next be examined carefully—

1. The sample must be free from soft pieces of stone or thin flaky pieces. This is readily ascertained by knocking the pieces together or trying to break them in the fingers.

2. The stone must be non-porous. To ascertain this, a sample must be carefully dried and weighed; then soaked in water and weighed again after quickly drying the surfaces on blotting paper. Samples of granite or gravel are obviously non-porous and need not be tested. Not more than 10 per cent absorption by weight should be allowed.

3. The addition of 2 per cent by weight of clay will make a dirty aggregate, while 5 per cent of clay makes a very dirty aggregate. The aggregate must be free from clay, loam, or organic matter. A sample is easily tested. Take a large glass jar and fill it one-third full of aggregate, add two-thirds of water, and shake. Excessive muddiness of the water or excessive deposit of clayey matter when allowed to settle, is easily detected. If a sufficiently clean aggregate cannot be purchased locally, then the material must be washed before use. (This is described later under "Preparing Aggregates.") The presence of clayey matter weakens the concrete, retards setting, and causes excessive shrinkage, and the use of dirty materials should not be permitted for good concrete work, however cheap they may be.

4. The size of the largest stones for mass concrete should not exceed 6 in. diameter. For average reinforced concrete work stones should pass a $\frac{3}{4}$ in. ring; while for very small sections, for example pre-cast fence posts or very thin floor finishes such as a $1\frac{1}{2}$ in. thick granolithic finish to a floor, the largest particles should pass a $\frac{3}{8}$ in. ring. All particles passing a screen having meshes $\frac{3}{16}$ in. square are reckoned as "sand," and must be excluded from the coarse aggregate. The aggregate should be well "graded"; that is, it should contain particles of all sizes ranging from $\frac{1}{4}$ in. up to the maximum size permitted. (The reason for this will be discussed under "Grading of Aggregates.")

Having examined all the various samples of local aggregates and compared the prices, a choice can be made after making sure that supplies are ample to keep pace with the work in hand.

Fine Aggregate ("Sand"). The choice of a sand for concrete is very similar to the choice of a coarse aggregate. The supply must be local, or transport charges will be excessive. Soft grains must be absent. Cleanliness is essential. A sample shaken up in a tumberful of water will soon decide this point (see Fig. 2). All the particles must pass a $\frac{3}{16}$ in. mesh sieve. Particles which will pass a sieve having 100 meshes to the inch (i.e. 10,000 meshes to the square inch) should be regarded as silt, and not more than 10 per cent of such small particles can be allowed in any sample. In any case, these small particles must be fine particles of real sand, and not clay or organic matter. Sand for important concrete work must be "well graded," but a discussion of the exact meaning of this term must be postponed until we have considered the general question of proportioning concrete. Screenings from crushed stone, particularly from crushed granite, may be used as sand, if not too dusty.

After a thorough examination of the various available samples and prices of each, a choice can be made.

Fig. 2 shows two samples of sand after a "cleanliness" test.

Mixed Aggregate. Sometimes it is cheapest to buy all or part of the aggregate in a naturally mixed form. In the neighbourhood of a navigable river it is often possible to buy river ballast "as dredged." This consists of a mixture of sand and shingle. In such a case a

large and representative sample should be shaken on a $\frac{3}{16}$ in. sieve, and the proportion of sand carefully measured. If the ballast "as dredged" is deficient in sand, then more sand must be bought and mixed with it. If there is an excess of sand, then more coarse material must be bought. In some cases it might be advisable (particularly if there were a great variation in the consignments of ballast "as dredged") to pass the whole of the material through a mechanical screen to separate the sand from the coarse material. The fine and coarse could then be re-combined in any proportion desired. The methods of testing and pricing mixed aggregates will be the same as for coarse and fine aggregates.

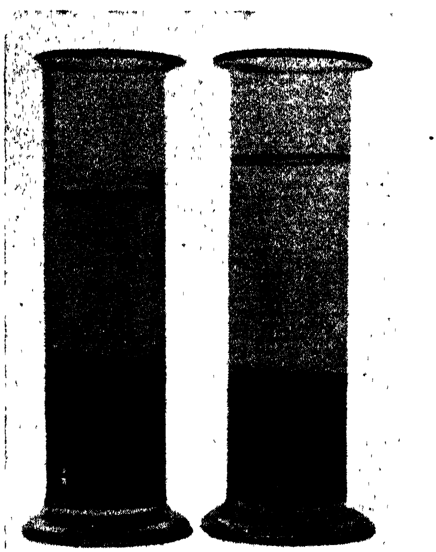


FIG. 2. SAMPLES OF SAND
Two samples after shaking up with water and standing 48 hours On left, dirty sand, showing coarser grains at bottom, fine grains above, and layer of fine silt on top On right, washed sand

PREPARING AGGREGATES. In this country there are, in most districts, firms who specialize in the preparation and supply of concrete aggregates. For small contracts it is the best plan to buy the aggregate ready prepared. For large contracts, for work carried out abroad or in undeveloped country, or where sand and gravel are obtainable on the site, it may be advisable or necessary for the concrete contractor to prepare his own aggregates. This preparation should not be lightly undertaken, as special plant is always necessary to carry it out successfully. Some contractors have the idea that washing and grading ballast consists of sprinkling each cart or wagon-load with a few pailfuls of water, and picking out the largest stones by hand. Not only is special plant indispensable, but a large pure water supply is essential. Too much stress cannot be laid on the fact that first-class concrete requires the use of first-class cement and *first-class aggregate.*

Fig. 3 shows a diagrammatic lay-out of washing and grading plant suitable for working a large ballast pit. The excavated material is fed on to a mechanically shaken screen *A* having a $\frac{1}{4}$ in. mesh. This screen is constantly sprayed with water from jets *B*. The sand and dirt are washed through the screen and fall into the trough *C*, whence they are swept into the sandpit *D*. The sand, being heavier, sinks to the bottom, while the dirt is carried in a state of suspension down the overflow *E*. An elevator *F* lifts the sand from the pit into the sand bin *G*, from whence it can be shot into carts, wagons, or lorries as required. The coarser material works down the screen into the pit *H*, whence it is taken by the elevator *I* and fed into the rotating screen *J*, which separates it into *K*, *L*, and *M* —the fine, medium, and coarse bins—*K* containing $\frac{3}{8}$ in. shingle, *L* containing $\frac{3}{8}$ in. to $\frac{3}{4}$ in. shingle, and *M* $\frac{3}{4}$ in. and upwards. The position,

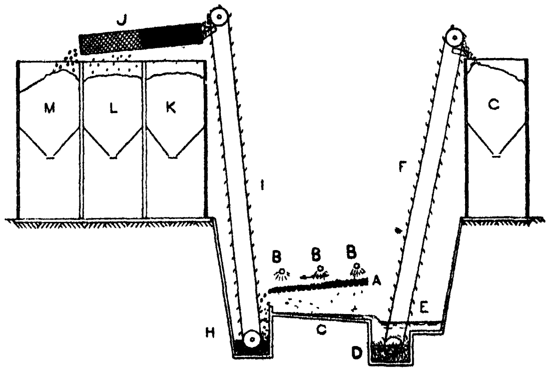


FIG. 3. DIAGRAM OF LAY-OUT OF WASHING AND SCREENING PLANT FOR WORKING LARGE GRAVEL PIT

number, and size of the screens, elevators, and bins may be varied to suit the particular job (see Fig. 4). If the aggregate is to be obtained from a quarry, then a number of stone crushers must be installed, but in this case it may suffice if the material is screened without washing. Indeed, in some cases, if it is found that the crushers produce always a uniform mixture of coarse and fine stuff, then they can be "set" to give a correctly proportional mixture, which,

with the addition of cement, produces concrete of the desired quality, making it unnecessary to use any screening apparatus. Sometimes the washing and screening plant may be combined with the gauging and mixing plant (see the next chapter), so that all concrete-making operations are concentrated at one spot.

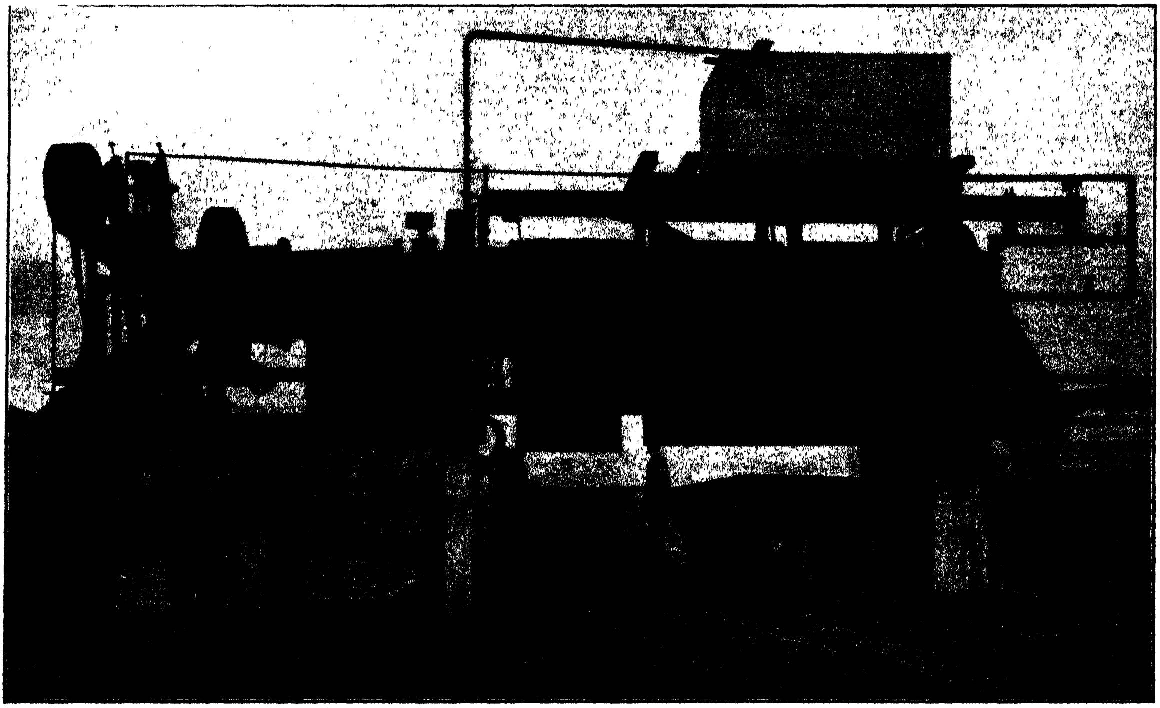


FIG. 4. SAND AND GRAVEL WASHER AND SCREEN
Patent Rotary Washer fed with Elevator (on left), with Rotary Screen discharging into tip wagons, constructed by Messrs. Hardy and Padmore, Ltd.

CEMENTS

Lime. Before the introduction of artificial Portland cement, the use of lime as a cement was almost universal. Lime does not "set" in the same sense as Portland cement, but depends on the action of the air to carry out a gradual hardening process. Ordinary lime will never set under water. Lime concrete is much weaker than Portland cement concrete, and is only used in countries where the latter cannot be obtained at a reasonable price. It cannot be used for large blocks, as the penetration of air to the centre would require an impossibly long time. At the present day, the world's supply of Portland cement is so large that the term "cement" invariably means Portland cement.

Portland Cement is an artificial compound of silicon, aluminium, calcium, and oxygen. Its manufacture demands a large amount of special plant, special chalk and clay, and expert supervision. In England, the contractor always buys his cement ready made from firms who specialize in its manufacture.

Only in foreign contracts would it be necessary to lay down cement-making machinery, and then an expert would be engaged to work it. The technical details of the manufacturing processes do not, therefore, interest the engineer or builder, but a general knowledge of them is useful.

Suitable limestone or chalk is mixed with clay, the two being thoroughly incorporated either by fine grinding together, or being mixed into a fine-textured slurry. The materials are then fed into the top end of a long, rotating, cylindrical kiln. As they pass down the kiln they are heated by hot flue gases to incipient fusion at a temperature of about 1,400° C., forming a clinker which is then ground into very fine powder. This consists of silicates of calcium

and aluminium. To this finely ground gypsum is added. The cement is then filled into sacks (in England usually twenty paper bags to one ton) and is ready for use.

When mixed with water the various silicates have the power of combining to form hydrated silicates, which crystallize out and harden. This process proceeds fairly rapidly at first, but more slowly later on. The setting is quite independent of the action of the air, and can very well take place under water. The setting must be sufficiently delayed to allow proper time for mixing the concrete and placing in position. It is also necessary that it should harden sufficiently to take a certain amount of load in a few days.

Testing Cement. British-made standard Portland cement, if bought from a reputable maker, is a high-class and very reliable product. It is usual in England to specify British Standard Portland cement. The full requirements of this specification are to be found in Specification No. 12, 1940, of the British Standards Institution.

The cement is first tested for fineness of grinding. This must be such that 90 per cent will pass a sieve made of B.S. mesh No. 170 (28,900 meshes per square inch).

Limits are set to the chemical composition, but the determination of these requires a skilled chemist.

Sample blocks, or *briquettes*, are made of sand, cement, and water, and are pulled apart in a testing machine. Briquettes made of three parts of sand to one part of cement shall show a tensile strength of at least 300 lb. per sq. in. when 3 days old, and at least 375 lb. per sq. in. when 7 days old. Normal cement must not take an *initial set* in less than 30 minutes. This represents the time during which the concrete may be transported and rammed into the moulds. The *final set*, when the cement cannot be impressed with the thumb-nail, must occur before 10 hours.

Quick-setting cement, which is occasionally required for work under flowing water, etc., must not take an initial set in less than five minutes, nor a final set in more than 30 minutes. For all general construction work the normal setting variety is always used.

Standard cement must also pass a test for soundness. It is essential that cement, when undergoing the chemical processes of setting, should neither expand nor contract, as this would shatter the concrete. It is, of course, essential that the cement is adequately protected from the weather during transport, and stored in a dry shed on the site. To decrease the risk, the cement should be used as soon after delivery as possible. Very old cement must be re-tested before use. The exact requirements of the British Standard Specification are liable to revision, but the latest specification issued may be obtained from the British Standards Institution, 28 Victoria Street, London, S.W.1.

Rapid-hardening Cements. These must be carefully distinguished from quick-*setting* cements. A good rapid-hardening cement sets slowly, but after having set it hardens rapidly. There are two distinct kinds, rapid-hardening Portland cement and Ciment Fondu. Rapid-hardening Portland cement (such as "Ferrocrete" or "Tunnelite") is very similar to normal Portland cement, but will develop as much strength in 7 days as normal Portland does in 28 days. It is a little more expensive, develops heat more rapidly during hardening, and therefore needs more careful curing. Ciment Fondu contains a much higher proportion of alumina, is kilned at a higher temperature and is darker in colour. It develops heat very rapidly during hardening, and if allowed to overheat its strength is destroyed. It therefore requires careful spraying with cooling water immediately it is set and cannot be used for large blocks. Test piles made with Ciment Fondu may be driven when 24 hours old.

To use rapid-hardening cement where a high early strength is required is now standard practice.

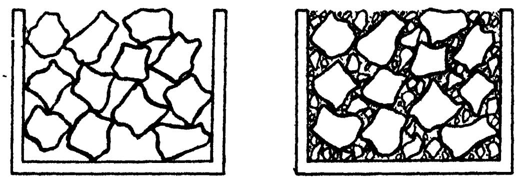
Water enters into chemical combination with cement, and the purity of the water supply must be absolutely insisted on. Water containing 2 per cent of sodium chloride may be used and is useful in some cases, as the salt prevents the concrete from freezing. Sea water containing dissolved sulphates is very detrimental, while water from peaty ground may contain organic acids which destroy the cement.

Chapter II—PROPORTIONING, GAUGING, MIXING, PLACING

PROPORTIONING

THE science of proportioning is the choice of the relative proportions of cement, sand, coarse aggregate, and water to give a concrete best suited to the particular work in view. The dominant economic factor is the relative cost. Washed sand or ballast costs only a fraction of the price of Portland cement; the relative amount of cement is, therefore, kept as low as possible.

Theory of Concrete Mixtures. If a vessel is filled with a large number of small spheres all of the same size, then there will be a certain number



ALL ONE SIZE GRADED

FIG. 5. VOIDS IN AGGREGATE

of small air spaces left between them. These vacant spaces are referred to as *voids*.

Similarly, if a bucket were filled with stones, or gravel, all of approximately the same size, we should have about 45 per cent voids. This result is independent of the size of the stones, so long as they are all of approximately the same size. If we filled a bucket full of dry sand, whose particles were of uniform size, we should still have about 45 per cent voids. We can measure the voids in broken stone by pouring water into a bucketful of stones until the bucket is just brimful. The volume of water must equal the voids. A better method, when using sand, ballast, or granite, is to weigh an accurate volume. All these materials consist mostly of quartz (silicon dioxide) which has a specific gravity of 2·67. Solid quartz weighs, therefore, $2{\cdot}67 \times 62{\cdot}5 = 167$ lb. per cub. ft. If a cubic foot of dry ballast weighs 90 lb., then it is only $\frac{90}{167}$ solid, i.e. 54 per cent, and must have 46 per cent voids.

If we take a bucketful of large stones, the voids are easily visible. If we add a few small stones, we can get them to trickle down between the large stones, and fill up a certain fraction of the voids. If we then add sand, this will run down the cracks between the small stones and fill up a further amount of the air space. Finally, if we add very finely-ground cement, this will find its way between the sand particles. Now water can still be added to fill up the very fine voids between the particles of cement, and during the process of setting a chemical combination takes place between the cement and the water, giving an absolutely solid concrete. A *graded* mixture, i.e. one containing particles of all sizes has, therefore, least voids and needs least cement to fill these voids. This is shown in Fig. 5. The left-hand diagram shows a vessel full of uniform stones with about 45 per cent voids. The right-hand diagram shows the effect of filling the voids with smaller stones and sand. A concrete having the greatest possible density is found to be the strongest and most watertight. The proportion of cement, sand, and coarse aggregate which will give us such a concrete, with the minimum cost, is that which has the *best graded* sand and aggregate, i.e. the exact mixture of coarse, medium, and fine particles which will pack closest into any given space.

This statement is not quite a complete picture as the pieces of aggregate should not actually touch one another, but should all be enveloped by and enclosed in a thin layer of cement. Nevertheless, it is the true basis of the theory of proportioning.

Grading of Aggregates—Analysis. A sand or a coarse aggregate (or a mixture of the two) is *analysed* by being passed through a series of sieves varying from a very fine mesh to a very coarse mesh. After prolonged shaking the percentage (by weight) retained on each sieve is carefully measured and a curve is drawn, the abscissae representing the sizes of holes in the various sieves, and the ordinates representing the percentage by weight which will pass each sieve.

A typical " nest " of small sand sieves is shown in Fig. 6. This consists of six separate sieves with a lid and a bottom container. They are made to fit together to form a tower. The upper sieve is shown separately resting on its side.

It is now usual to follow American practice and use six sieves for sand analysis (American

Tyler Standard, Nos. 4, 8, 14, 28, 48, and 100). If these are unobtainable, B.S.S. No. 410, sieves $\frac{3}{16}$ in., 7, 14, 25, 52, and 100, may be used. The writer has an 8 in. diameter next of Tyler sieves for office use. The small portable sieves in Fig. 6 are useful for approximate work out of doors. To analyse a sample of sand with 8-in. sieves, take about 4 lb. weight of sand, dry carefully, and remove stones over $\frac{3}{16}$ in. (if any), as these should be reckoned part of the coarse aggregate. Build the sieves up into a tower as shown in Fig. 6. Place $\frac{1}{2}$ lb. sand in the top and shake for five or ten minutes. Dismantle the sieves and pour the residue on each sieve into a small separate pile. Repeat until the whole 4 lb. has been treated. We shall then have seven small piles of sand, each of which must be carefully weighed. Suppose we find—

Amount			
retained on No. 4 sieve (top),	0·6 oz.	=	1·0%
,, ,, 8 ,,	6·0 oz.	=	9·3%
,, ,, 14 ,,	5·4 oz.	=	8·3%
,, ,, 28 ,,	8·5 oz	=	13·0%
,, ,, 48 ,,	27·3 oz.	=	42·0%
,, ,, 100 ,, (bottom),	16·2 oz.	=	24·9%
passing 100 sieve	1·0 oz	=	1·5%
Total	4 lb. 1 oz.	=	100·0%

Total amount passing—

No. 4	sieve	= 99%	(clear aperture 0·185 in.)
,, 8	,,	= 89·7%	(,, ,, 0·093 in.)
,, 14	,,	= 81·4%	(,, ,, 0·046 in.)
,, 28	,,	= 68·4%	(,, ,, 0·0232 in.)
,, 48	,,	= 26·4%	(,, ,, 0·0116 in.)
,, 100	,,	= 1·5%	(,, ,, 0·0058 in.)

We can now plot the curve in Fig. 7. This is an excellent sand with a well-shaped grading curve. If we add the six dimensions marked A, B, C, D, E, and F and divide by 100, we get what is called the *fineness modulus*. In this case the values are—

$$
\begin{aligned}
A &= 1{\cdot}0\% \\
B &= 10{\cdot}3\% \\
C &= 18{\cdot}6\% \\
D &= 31{\cdot}6\% \\
E &= 73{\cdot}6\% \\
F &= 98{\cdot}5\% \\
\hline
& 233{\cdot}6\% \quad \text{Fineness Modulus} = 2{\cdot}34
\end{aligned}
$$

The fineness modulus is not an exact mathematical function, but gives a fair idea of the general grading. For first-class reinforced concrete work a fineness modulus of 1·0 is too small. Sands with a fineness modulus of 1·5 may be used if the cement content is increased. A modulus of 2·0 to 2·5 is good, but a modulus over 3·0 is too coarse. Fig. 8 shows analysis of a coarse and a fine sand.

Sieve analysis is, of course, only a means to an end. Test cubes should be made of all likely sources of sand and coarse aggregate.

Theoretically, the analysis curve should be extended to include the coarse aggregate, but a little practice will enable the grading of coarse stuff to be judged by eye.

WATER. The quantity of mixing water is a most highly important item. Just sufficient should be added to produce a workable mixture. This is best judged by eye. A little experience will teach the novice. The so-called *slump* tests are difficult to apply, give no real indication of the workability, and are not recommended for practical work. It must be remembered that sand and ballast normally contain a certain variable amount of moisture, and this must be taken into account. When starting up for the day, the first few batches should be watered by trial and error. When the correct amount of water for each batch has been found, the mixer tank should be set to deliver that exact amount to each subsequent batch. Over-wet concrete is weak and porous. Dry concrete is very difficult to ram into moulds and is apt to leave air pockets. The theoretical amount of water necessary to form the chemical compound with the cement is found to have little or no bearing on practical concreting.

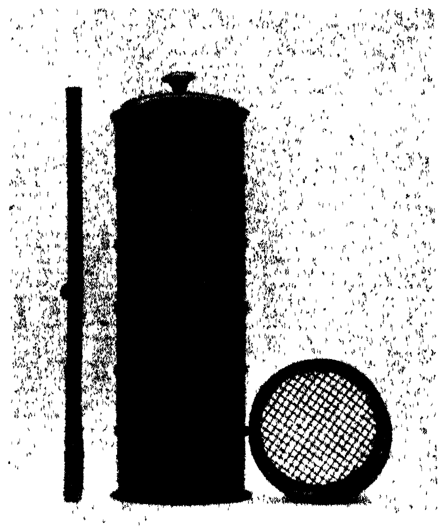


FIG. 6. NEST OF 4 IN. DIAMETER SAND SIEVES

SPECIFYING PROPORTIONS—SAFE STRENGTHS. The materials are measured by volume. For

small jobs it is usual to specify an arbitrary mixture for each kind of concrete required. The amount of cement, sand, and coarse aggregate for different uses may be taken as follows—

Foundation and mass concrete work—1 : 3 : 6; safe compressive working stress 500 lb. per sq. in.
Reinforced concrete—1 : 2 : 4; safe working stress 750 lb. per sq. in.
Watertight work, etc.—1 : 1½ : 3; safe working stress 850 lb. per sq. in.

The above figures are for standard Portland cement. For special cements the engineer must consult the makers of each particular brand.

For large and important works the whole of the available aggregates and sands should be carefully examined and analysed. Test-cubes of concrete can then be made, using samples of the best materials available with varying proportions of cement. The resulting safe compressive stress may be taken as one-quarter of the crushing strength at the age of one month. In this way it is possible, if very good aggregates are available, to use less cement or work to a higher safe stress. It must be remembered, however, that all natural sand and gravel pits vary from one part of the pit to another. It is not safe to rely on a weaker mixture unless numerous samples of sand and gravel are taken from all parts of the pit which it is proposed to use.

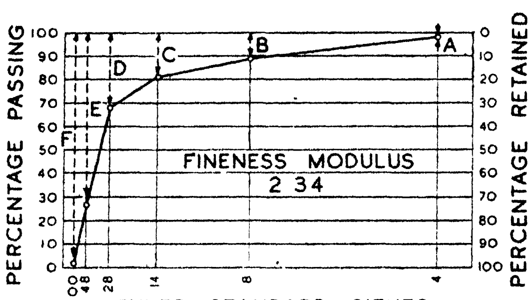


FIG. 7. SAND ANALYSIS

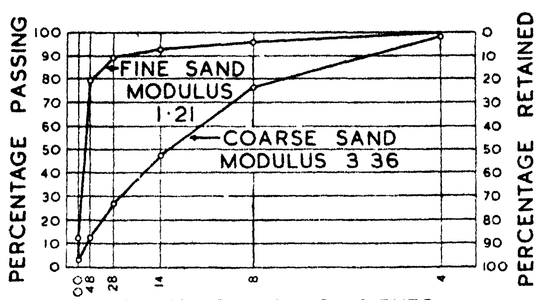


FIG. 8. SAND ANALYSIS

QUANTITIES OF MATERIALS REQUIRED PER CUBIC YARD. Cement is invariably sold by weight; but sand, shingle, and ballast are sometimes sold by weight and sometimes by volume, according to local custom and method of delivery. It is easiest to calculate first the volume of all materials, then calculate the weight if necessary. For all normal mixes, it may be assumed that the volume of finished concrete in place is two-thirds of the sum of the volumes of the cement, sand, and shingle measured separately. If we mix A volumes of cement with B volumes of sand and C volumes of shingle, we shall make $0{\cdot}66\ (A + B + C)$ volumes of concrete. Hence a mix by volume of $A : B : C$ concrete requires—

$$\frac{A}{0{\cdot}66\,(A + B + C)} \text{ cub. yd. of cement.}$$

$$\frac{B}{0{\cdot}66\,(A + B + C)} \text{ cub. yd. of sand.}$$

$$\frac{C}{0{\cdot}66\,(A + B + C)} \text{ cub. yd. of shingle.}$$

to make one cube yard of concrete.

To convert these into weights, take 1 cub. yd. of normal Portland cement as 1·08 tons; 1 cub. yd. of rapid-hardening cement as 1 ton; 1 cub. yd. ciment fondu as 1·08 tons; 1 cub. yd. of sand as 1·20 tons; and 1 cub. yd. of ¾ in. shingle as 1·15 tons. The figure 0·66 is an average value. Take a figure of about 0·63 for rich mixes and 0·68 for poor ones.

When using pit ballast or river ballast "as dredged" the materials are to some extent mixed. If we mix D volumes of cement with E volumes of ballast we shall make $0{\cdot}66\ (D + 1{\cdot}10E)$ volumes of finished concrete. Hence a ballast concrete mixed $D : E$ by volume requires—

$$\frac{D}{0{\cdot}66\ (D + 1{\cdot}10E)} \text{ cub. yd. of cement.}$$

$$\frac{E}{0{\cdot}66\ (D + 1{\cdot}10E)} \text{ cub. yd. of ballast.}$$

The figure 1·10 is a fairly low one as some ballast may give a figure of 1·15.

An excellent check at all times is that the combined weight of cement, sand, and shingle

per cubic yard of finished concrete is very nearly 1·70 tons.

EXAMPLE. An engine foundation is made of 1 : 2½ : 5 concrete with normal Portland cement, sand, and ¾ in.

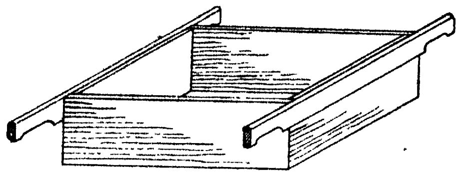


FIG. 9. GAUGE BOX

shingle. What materials are required per cub. yd. of finished concrete?

SOLUTION—

$$\frac{1}{0{\cdot}68\,(1 + 2\tfrac{1}{2} + 5)} \text{ cub. yd. cement} = 0{\cdot}173 \text{ cub. yd.}$$

$$\frac{2\tfrac{1}{2}}{0{\cdot}68\,(1 + 2\tfrac{1}{2} + 5)} \text{ cub yd sand} = 0{\cdot}432 \text{ cub. yd.}$$

$$\frac{5}{0{\cdot}68\,(1 + 2\tfrac{1}{2} + 5)} \text{ cub yd. shingle} = 0{\cdot}865 \text{ cub. yd}$$

Or 0·187 tons cement, 0·52 tons sand, and 1·00 tons ¾ in. shingle (total 1·707 tons).

EXAMPLE. A heavy reinforced-concrete deck is made of 1 : 4 ballast concrete, with Thames ballast "as dredged" and rapid-hardening cement. What materials are required per cub. yd of concrete?

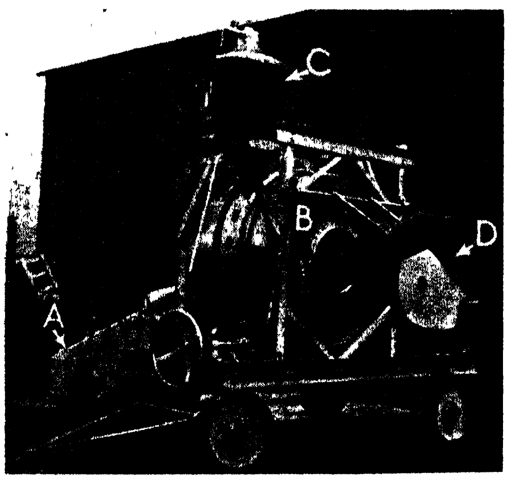


FIG. 10 "VICTORIA" 32/21 PETROL DRIVEN CONCRETE MIXER

A = Charging hopper *C* = Adjustable water tank
B = Rotating mixing drum *D* = Motor

SOLUTION—

$$\frac{1}{0{\cdot}64\,(1 + 1{\cdot}10 \times 4)} \text{ cub. yd. cement} = 0{\cdot}29 \text{ cub. yd.}$$

$$\frac{4}{0{\cdot}64\,(1 + 1{\cdot}10 \times 4)} \text{ cub. yd. ballast} = 1{\cdot}16 \text{ cub. yd.}$$

Or 0·29 tons of rapid-hardening cement and 1·16 cub. yd. of ballast.

If the ballast contains too much or too little sand, extra shingle or extra sand may be added. Such hybrid mixes may be treated by combining the methods given above.

GAUGING AND MIXING

These two operations are discussed together because the method of doing the one determines the method of doing the other. Gauging is the measuring of materials on the site, and up to the present it has always been done by volumes.

Hand Mixing. The mixing requires a stout timber platform 15 ft. square. The gauging is done by means of a bottomless gauge-box, as in Fig. 9. The box should be made of suitable size so that it contains an exact amount when filled completely, the excess material being "struck-off" by drawing a piece of scantling across the top edges. Boxes to be "filled up to a mark on the side" or "heaped" are much less accurate and should not be used. A separate small box is kept for cement.

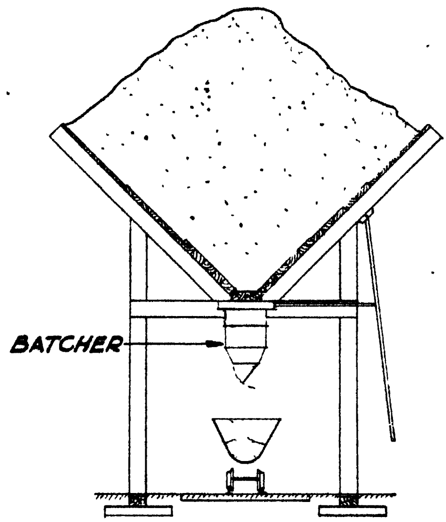


FIG. 11. BATCHER FITTED TO GRAVEL BIN

The shingle and sand are first measured out and the cement is spread on top. The materials are then turned over completely three times dry with shovels (not rakes). Water is added through a fine rose and the whole turned over three times at least before being shovelled into wheelbarrows or buckets for jenny-wheels, etc.

Hand mixing is only employed when concrete is required in small quantities at a time. Good hand mixing is inferior to good machine mixing, and is more expensive on large jobs.

Machine Mixing. The revolving drum batch-type mixer is by far the most popular machine. An excellent example is the petrol-driven "Victoria" mixer (made by Messrs. Stothert & Pitt, Ltd.), shown in Fig. 10. The measured materials are shot into the charging hopper, the broad end of which is then raised by the motor, causing the materials to run into the circular hole in the drum. There is a series of vanes which, as the drum is rotated, carry the materials up and drop them again, cutting and mixing the whole mass thoroughly. An adjustable water tank on top of the machine can be set to deliver a given quantity of water to each batch. The mixed concrete is delivered down the spout from the near side of the machine.

For large mixers running continuously night and day, steam is the most reliable.

Gauging sand and coarse aggregate for a mixer is usually done by means of wheelbarrows, which should be specially made to contain an exact amount when filled and "struck-off." The best policy is to use a sufficiently large mixer to take at least one complete bag of cement to each batch, thus ensuring an exact amount of cement. One minute in a good mixer is enough to ensure thorough mixing.

For large contracts, it is the best plan to store the gravel in a bin and use a mechanical *batcher* for measuring it out (see Fig. 11). Details of a Blaw-Knox batcher are given in Fig. 12. This consists of an adjustable steel box, having an upper and a lower door. The lower door is closed and the upper one opened, allowing the box to fill. The upper door is closed, thus "striking off" an exact amount of material. Opening the lower door then discharges the measured batch into a wagon, lorry, or skip, or directly into the mixer. When measuring sand, it should be remembered that very dry sand has the same volume as very wet sand, but damp sand has a volume greater than either. The Blaw-Knox Co. make a sand *Inundator*, which measures out an exact batch of *inundated* sand, i.e. sand whose voids are completely filled with water. This not only keeps the volume constant but also gives control over the mixing water, as it eliminates the greatest unknown factor, i.e. the variable amount of moisture contained in the average sand-heap.

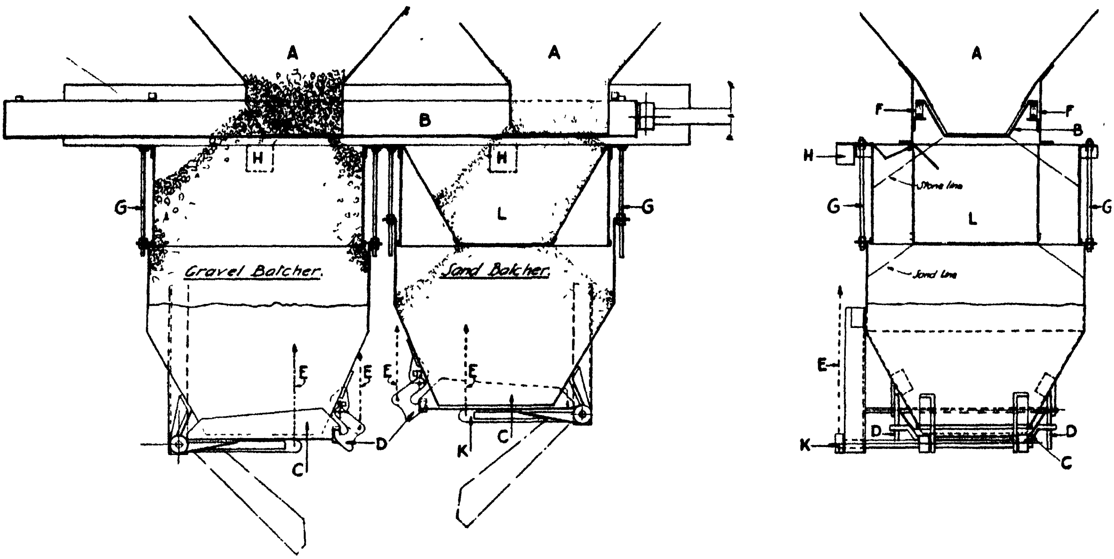


FIG. 12. BLAW-KNOX TWIN BATCHERS

A = Stone and sand bunkers
B = Top striking-off gate
C = Outlet door
D = Door catches
E = Operating ropes
F = Gate rollers
G = Adjusting bolts
H = Load indicator
K = Lever arm operating door
L = Sand batcher reducing collar

HANDLING AND PLACING

Concrete may be transported on the level in barrows or special steel concrete carts. For work above ground level on big jobs a mast-hoist

plant with chutes may be used. The mixer discharges into a bucket which is hoisted up the mast and made to discharge into the top

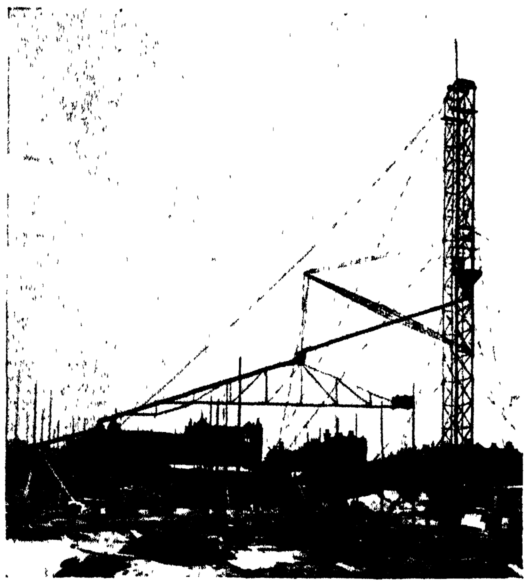


FIG. 13. "INSLEY" CONCRETE PLACING PLANT
Steel Tower with Quick Shift Hoist Bucket (shown discharging into Tower Receiving Hopper) and 50 ft Boom and Counterweight Chutes

end of a series of metal chutes. By moving the end of the lowest chute the concrete can be directed to flow to any part of the job.

Fig. 13 is a photograph of an Insley plant in action. For successful chuting a mix with plenty of sand and cement is necessary. Foremen are apt to use too much water and the use of chutes is dying out. Modern practice is to use an Ace hoist or Neal's crane to do the vertical lifting, and do all horizontal moving with barrows or prams running on scaffolding.

All concrete must be well rammed in place. Mechanical vibration is discussed in Chapters VIII and IX. Where concrete has to flow into narrow places or round heavy reinforcement, it may be made a little wetter, using a smaller maximum size of coarse aggregate, if necessary. Concrete should never be placed if the air temperature is lower than 34° F., or if the stock piles of sand and ballast are frozen. In countries with long and hard winters, methods of heating the materials, heating the forms, and heating the structure with braziers have been tried. The alarming number of bad accidents points to the conclusion that the precautions taken were inadequate. Concrete should be allowed to set, then kept damp for a few days, being covered at night to prevent freezing.

The Concrete Chain. The process of making concrete may be regarded as a chain of twelve

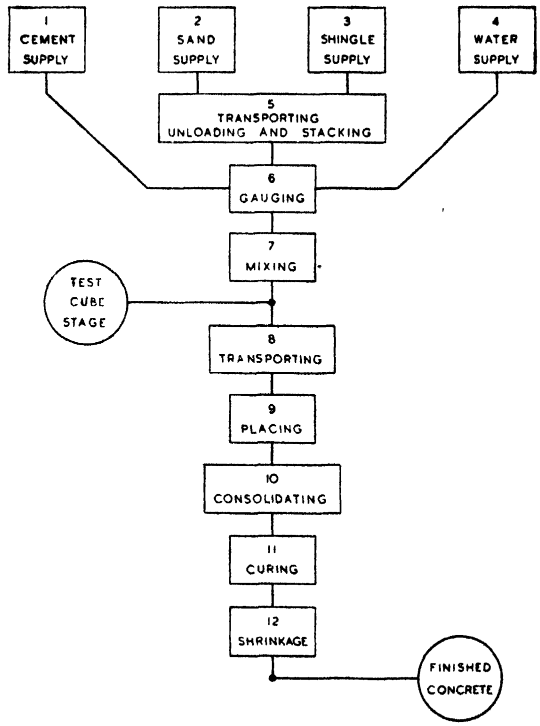


FIG. 13A. THE CONCRETE "CHAIN"

links, the strength of the chain depending on its weakest link. Writers on the subject are apt to over-emphasize one link and ignore the other eleven. The reader should always try to keep all twelve links in mind, allotting the correct relative importance to each (see Fig. 13A).

Chapter III—PLAIN CONCRETE STRUCTURES

Strength. For very large jobs the safe strength should be determined by experiment (see Chapter II, "Specifying Proportions—Safe Strength"). For smaller works the safe working strengths given in Table I should not be exceeded.

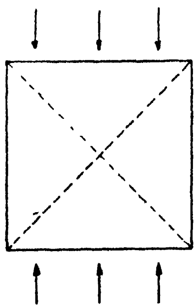


FIG. 14

TABLE I

SAFE STRENGTHS OF CONCRETE

	1 : 3 : 6 Mixture	1 : 2 : 4 Mixture	1 : 1½ : 3 Mixture
	per sq. in.	per sq in	per sq. in.
Safe compressive stress	500 lb.	750 lb.	850 lb.
Safe tensile stress .	nil	nil	nil
Safe beam shear stress	50 lb.	75 lb	85 lb.
Safe punching shear stress . . .	100 lb.	150 lb.	170 lb.

The strength of plain concrete varies very nearly as the percentage of cement in the mixture, and the strength of intermediate mixtures may be based on this assumption. The coefficient of expansion per 1° F. rise in temperature is about ·000006. The use of mass concrete is limited by its very low tensile strength; this, of course, makes it impossible to use plain-concrete beams. Piers, walls, and dams made of plain concrete rely entirely on their own weight for their stability; thus plain concrete is only used for massive structures

The safe compressive stresses given in Table I will only apply to isolated piers of plain concrete if the height is less than four times the least thickness. The practical strength of isolated piers higher than this may be taken as equal to the strength of isolated brickwork piers of similar size.

This drastic reduction in the safe working stress is due to the fact that plain concrete, having no tensile strength, cannot resist accidental blows, unexpected transverse loads, eccentric loading, etc. The standard method of testing the strength of concrete in this country is by crushing a 6 in. cube in a testing machine. Failure occurs mainly by shearing at an angle of approximately 45°.

The cube never fails by direct compression, but gives way owing to the fact that there is a heavy shearing force along planes inclined at 45° to the line of thrust (see Fig. 14). Shearing force is always accompanied by diagonal tension, and plain concrete is very weak in tension. The failure of a test cube, although caused by applying a *compressive* load, is really due to *tensile* weakness. The four sides of the cube crush out (along the dotted lines), leaving a pyramid-shaped piece at the top and bottom. Fig. 15 shows parts of two typical test cubes after crushing.

Plain-concrete structures are usually of such massive proportions that the ordinary theory of elastic bending does not apply. Although in general we do not rely on the tensile strength of plain concrete to act as a beam, it is found by experiment that a footing made of plain concrete can cantilever out provided that the projection is less than 0·577 times the thickness, that is, if the line of spread is steeper than 60° (see the remarks on "Footings" later).

Growth of Strength with Age. Although concrete becomes solid as soon as the cement sets, it is incapable of carrying any load until it has been allowed to harden. This hardening process proceeds more rapidly in warm weather than in cold, the air temperature being the main factor. Minor disturbing causes are the amount of mixing water used, and the cleanliness of the aggregate. A very dry mixture hardens a little more rapidly than a medium wet one. Traces of clay or silt in the ballast or sand retard hardening. A gravel concrete mixed 1 : 2 : 4 with standard Portland cement should show a compressive strength of at least 2,250 lb. per

sq. in. when 28 days old, if kept at a temperature of 60° F. The strengths at 3 days, 7 days, and 14 days will be about 550, 1,100, and 1,700 lb. per sq. in., respectively. The strengths of other mixtures may be taken *pro rata*. All the above values are for standard Portland cement. Plain-concrete structures are never subject to heavy transverse loads, and in average weather

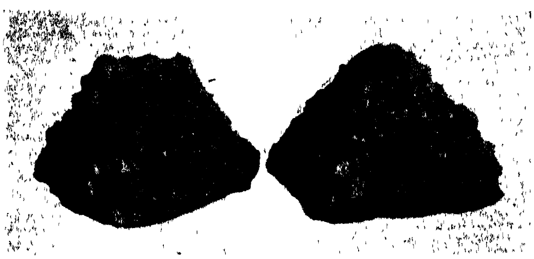


FIG. 15. REMAINS OF TWO 6 IN. CUBES TESTED BY MR. R. H. H. STANGER, A M.Inst.C E.

conditions the centering may be removed the day after the concrete is laid. The hardening is often assisted by the fact that the chemical combinations taking place during setting cause a rise of temperature which persists, due to the massive type of structure used.

In a narrow trench in stiff ground the sides of the trench will act as centering. The thickness of the footing must be sufficient to "spread" the load at 60° over the required width.

Fig. 16 shows a section through a footing laid on a porous foundation, a footing cast in a narrow trench, and a footing spreading a heavy load. In this last case the method of determining the minimum thickness of footing is shown. The wall carries a load of 12 tons per foot run, the wall footing being 3 ft. wide. The foundation can only support a load of $1\frac{1}{2}$ tons per sq. ft. It is necessary, therefore, to make the footing about 8 ft. wide. The concrete must be of sufficient thickness to "spread" the load from a width of 3 ft. on top to a width of 8 ft. below at an angle of 60°. The "spread" on either side is, therefore, 2 ft. 6 in., and the necessary thickness, by geometry, is 2 ft. 6 in. $\times \sqrt{3}$, which is, say, 4 ft. 6 in.

Pile Caps. Pile caps are designed in the same way as footings, with the additional precaution that the thickness must always be sufficient to prevent the piles *punching* through the concrete. Plain-concrete footings are usually so massive that punching is not to be feared, but the strength should, nevertheless, always be checked as a safeguard. In addition

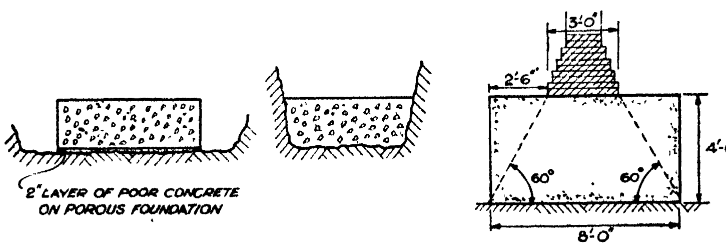


FIG. 16

Footings. Wall or column footings should not be less than 9 in. thick, and preferably not less than 12 in. thick. The concrete should not be weaker than 1 : 3 : 6, which is the minimum richness for any concrete expected to carry loads. If laid on a very porous foundation, the mixing water will trickle away, taking the cement and fine sand with it. To prevent this it is necessary, before placing the footing concrete, to cover the foundation with a thin skin of poor concrete about 2 in. thick. After this has set, the full specified thickness of footing is then laid. If it is necessary to excavate a trench wider than the footing, boards will be required as centering along the edges.

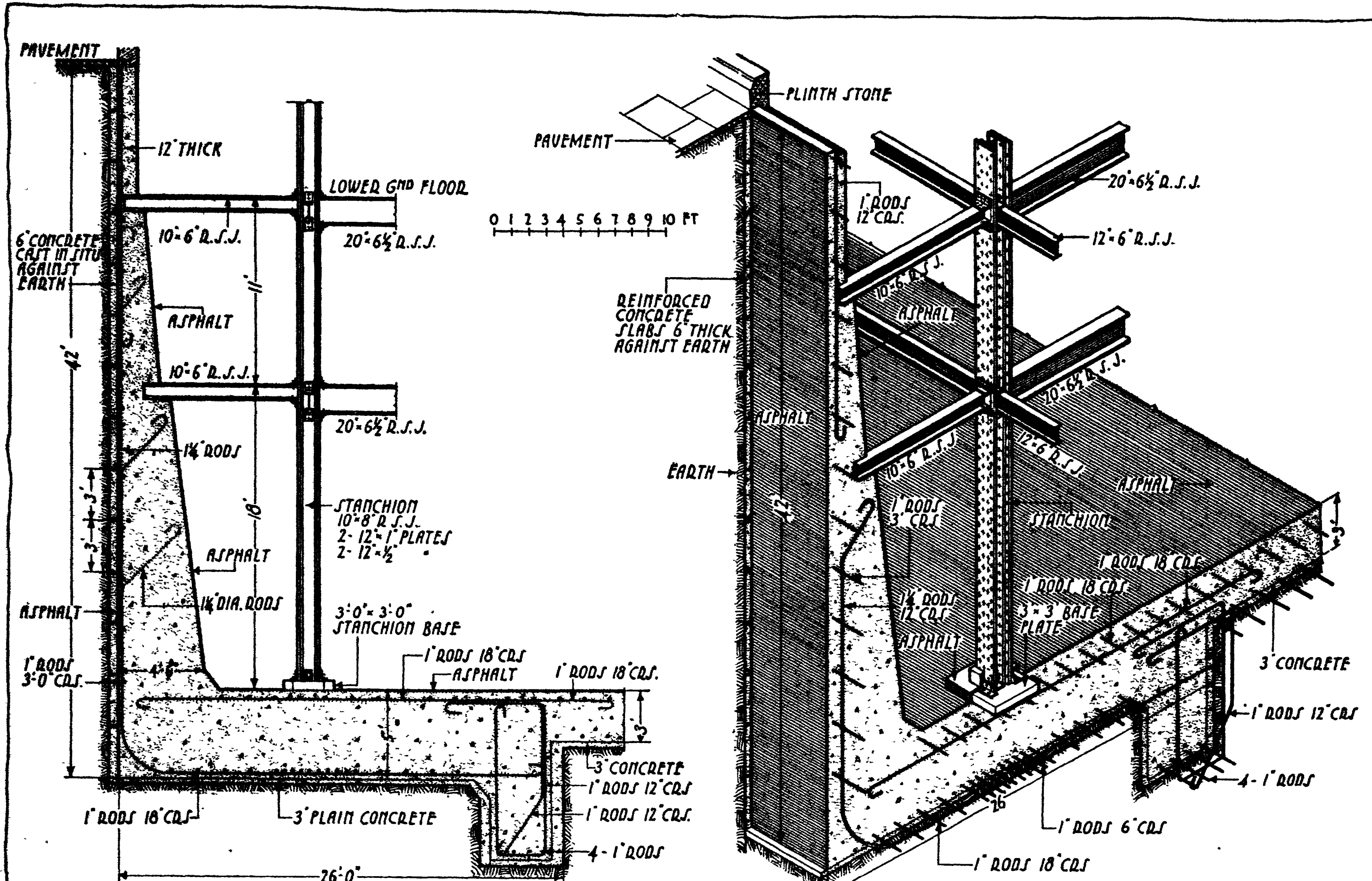
to this, the bearing pressure of the piles on the underside, and the bearing pressure of the stanchion base on top, must be checked.

EXAMPLE. A stanchion carries 480 tons, which is to be transmitted to a group of sixteen 12 in. × 12 in. piles arranged in four rows of four. The stanchion base is 3 ft. 6 in. × 3 ft. 6 in., and the piles are driven 12 in. apart clear. Design a suitable plain-concrete cap.

SOLUTION. The maximum spread will be on a diagonal to cover the corner piles. By geometry, this distance is $\sqrt{2}$ (3 ft. 6 in. − 1 ft. 9 in.) = 2·48 ft.

Minimum thickness x (see Fig. 17) is $\sqrt{3} \times 2{\cdot}48$ = 4 ft. 6 in. nearly.

Allowing for embedding the pile heads 3 in. into the



CONCRETE RETAINING WALL

E.G.W.

underside of the cap, an overall thickness of 4 ft. 9 in. would be suitable.

The intensity of bearing under the base plate is 480 tons on 3 ft. 6 in. × 3 ft. 6 in., which is

$$\frac{480 \times 2240}{42 \text{ in.} \times 42 \text{ in.}} = 610 \text{ lb. per sq. in.}$$

The intensity of bearing over the head of one pile is 30 tons on

$$12 \text{ in.} \times 12 \text{ in.} = \frac{30 \times 2240}{12 \text{ in.} \times 12 \text{ in.}} = 465 \text{ lb. per sq. in.}$$

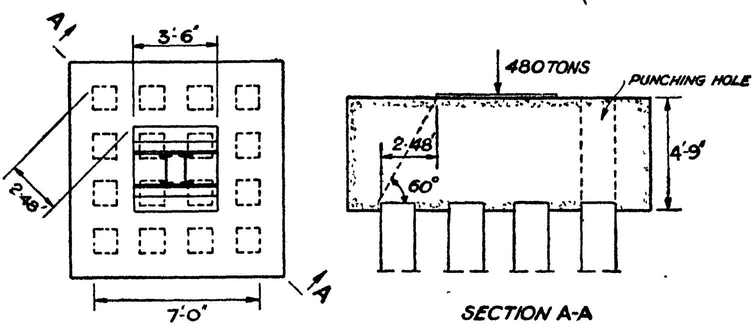


FIG. 17

If one of the outer piles were to punch a hole through the cap, the piece of concrete punched out would be 12 in. × 12 in. × 4 ft. 6 in., as indicated by the dotted line in Fig. 17. The punching force is 30 tons, and the total area of the four sides of the hole is 4 × 12 in. × 54 in.

The intensity of punching shear is

$$\frac{30 \times 2240}{4 \times 12 \times 54} = 26 \text{ lb. per sq. in.}$$

The cap could be made of 1 : 2 : 4 concrete.

Retaining Walls—THEORETICAL. As no tension can be permitted, the wall will have to rely for stability on its weight. The condition that no tension shall occur is that the line of thrust lies inside the middle third of any horizontal section. This condition is fulfilled if we use the minimum theoretical wall shown in Fig. 18. The wall is divided into two parts—the *Stem* (i.e. the part above the lower ground level) and the *Footing*. The stability at any section x–x of the stem, taken at a depth h, is indicated by the right-hand diagram. If the lateral pressure at a depth h is ph, then the total overturning pressure above section x–x is $\frac{1}{2}ph^2$. The stabilizing forces are the weight of the triangle of wall and the weight of the triangle of earth lying between the concrete and the *virtual back* of the wall.

Fig. 19 gives the value of θ corresponding to different values of p for all different values of the batter of the front face of the wall. Fig. 20 gives the values of the corresponding factor of safety against overturning.

Whatever batter we choose to put on the face of the wall, these two graphs give us at once the minimum triangular section we may use for the stem of the wall. Below the lower ground level the footing may project forward to form a *toe*, provided that we keep within the 60° line (see "Plain Concrete Footings"). The back of the footing may be made vertical or extended, as shown by the dotted line, to form a *heel*. The amount of projection required by the toe and heel will be determined by the maximum allowable pressure on the foundation. (For the methods of calculating the stability of walls and masonry dams, see the section on "Civil Engineering.")

PRACTICAL. In practice it is easier, instead of making the back of the wall on a slope, to make a series of short vertical faces. This increases the amount of concrete slightly, as the practical section must not cut into the theoretical triangle. The front face of the toe will also be made vertical. For the sake of

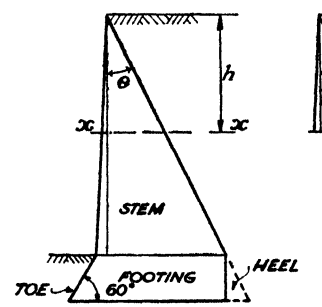


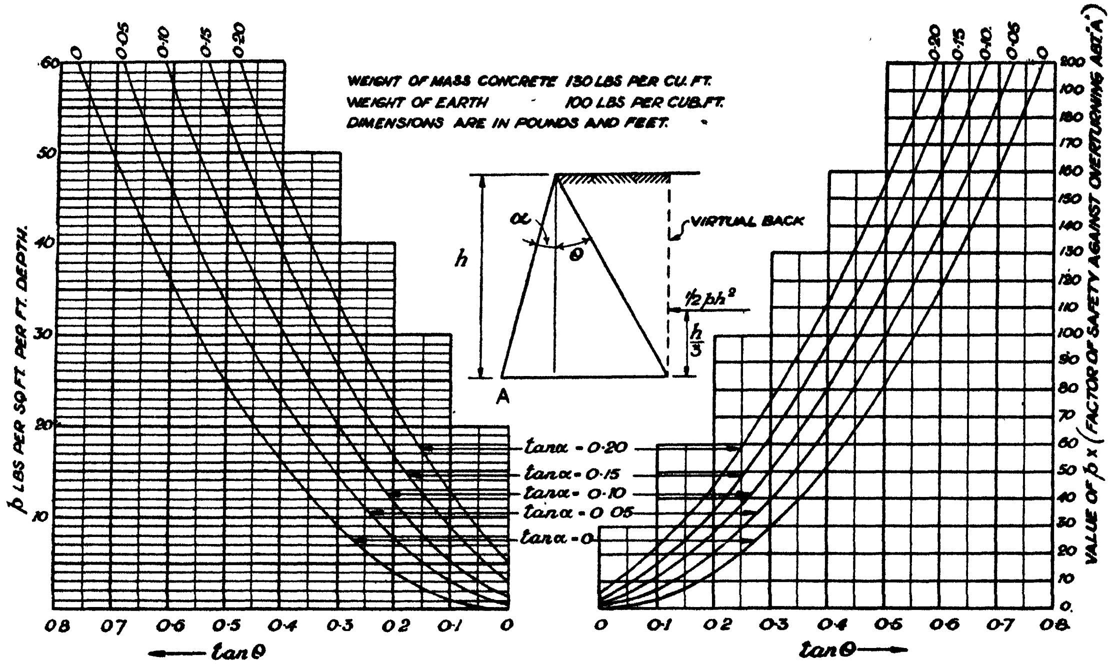
FIG. 18

appearance a coping will be added. If there is a surcharge due to superload on the upper ground level, the diagrams in Figs. 19 and 20 may still be used by adding 1 ft. to the height of the wall for every 1 cwt. per sq. ft. of surcharge. An example will make the matter clearer.

EXAMPLE. An area wall is to be in mass concrete and must be self-supporting. The depth of the area is 25 ft. and there is a good foundation 4 ft. below the

area. There is a superload of 1 cwt. per sq. ft. on the upper ground level (i.e. the pavement). The lateral pressure from the earth is estimated at 25 lb. per sq. ft. per foot of depth. The front face of the wall is to have a batter of 1 in 20 (= ·05).

SOLUTION. From Fig. 19 we have *tan* $\theta = 0{\cdot}42$.
Maximum value of $h = 25$ ft. + 1 ft. (for superload) = 26 ft.
Width of wall at area level = $h(\tan \alpha + \tan \theta)$ = $26\,(0{\cdot}05 + 0{\cdot}42) = 12{\cdot}2$ ft., say 12 ft. 3 in.



FIGS. 19 AND 20. MASS CONCRETE RETAINING WALLS
Fig. 19 shows the minimum value of *tan* θ to resist any lateral pressure p and keep the line of thrust always inside the middle third.
Fig. 20 gives the factor of safety against overturning bodily

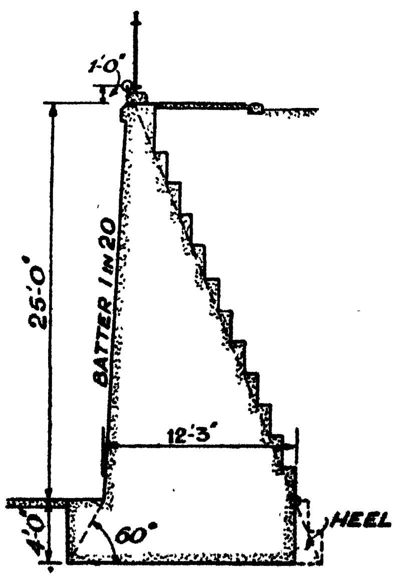


FIG. 21

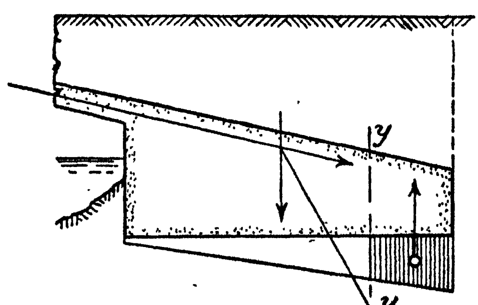


FIG. 22

Set up a point 1 ft. above pavement level and draw the dotted line in Fig. 21. This gives us the minimum theoretical stem of the wall. From the lower ground level draw a line inclined at 60° to the vertical. This determines the maximum size of toe we can use. The back of the footing is drawn vertical in the figure. Whether this is satisfactory or not must be determined by calculating the intensity of pressure under the toe. The addition of a heel (shown dotted) would reduce

the pressure. (It must be remembered that practical retaining walls never overturn and never slide forward over the foundation. *Stability failures are always due to excessive bearing pressure.* In some cases the consequent yielding of the foundation causes the toe to sink and the wall in consequence leans forward. In other cases, where the foundation is on clay, the excessive pressure causes the earth to squeeze out and flow forward, carrying the wall with it.)

The factor of safety against overturning for the section just above the footing is given by Fig. 20, i.e. for a value of $\tan\theta = \cdot 42$ and a batter of 1 in 20, $p \times$ (factor of safety) $= 70$. As p actually is 25, then the factor of safety against overturning is 2·8.

The back of the wall could very well be brought up in vertical lifts of 2 ft., as shown in the figure.

Abutments. On good foundations where the weight of the abutment itself is not important, then mass concrete provides the soundest construction. Although generally called "mass concrete" abutments, they usually require a layer of steel reinforcement near the bottom. Another point likely to cause anxiety is the beam shear in the tail end of a long shallow abutment.

This case is illustrated in Fig. 22. The total upward pressure to the right of section *y–y*, less the self weight of the concrete and earth filling above the abutment, must not exceed the safe beam shear on the section *y–y*. If the abutment were 30 ft. wide and 6 ft. deep at section *y–y*, being composed of 1 : 2 : 4 concrete, then the shear strength at the section would be $30 \times 12 \times 6 \times 12 \times 0{\cdot}66 \times 75$, i.e. 1,280,000 lb. The unbalanced upward force to the right of the section must not exceed this amount.

Roads. Some concrete roads have no steel, and some have such a light mesh of steel that they cannot fairly be described as reinforced. If laid on a really hard foundation, and laid in short lengths of 20 ft. to 30 ft., no steel is required. Granite aggregate or hard broken stone is usually used for the wearing surface in preference to shingle, firstly because the shingle being smooth does not give such a good grip for tyres, and secondly because nearly all shingle contains a small percentage of softer stones that crush out under traffic. A total thickness of 6 in. to 8 in., depending on the traffic and strength of foundation, with the bottom 1 : 2 : 4 shingle concrete and the top 2 in. 1 : $1\frac{1}{2}$: 3, using $\frac{3}{4}$ in. to $\frac{3}{16}$ in. granite aggregate, will give a good road. The top layer must follow straight on after the bottom, and the surface must be well tamped as it is screeded. Machines can now be purchased to do this mechanically. If the foundation is porous, a preliminary layer of 2 in. of mass concrete should be laid. Good sharp clean silica sand is required, and the concrete should be as dry as possible. Dirt, silt, very fine sand or excess water works up to the top and spoils the wearing surface. After laying, the road must be carefully covered with matting or damp sand for a few days.

Advantages of Plain Concrete. When comparing plain concrete with reinforced concrete the advantages, at first sight, would seem to be always with reinforced concrete. In order to develop any spanning action in plain concrete, the line of "spread" must be kept within a steep angle as in Figs. 16 and 17 and footings and pile caps in plain concrete must be made in one continuous operation. The cap in Fig. 17 contains 14 cub. yds. of concrete and must be concreted in one continuous pour (a 7/5 mixer turns out about one-sixth of a cub. yd. per batch. At 20 batches per hour it could pour 14 cub. yds. in $4\frac{1}{4}$ hours). If it were made in two or three layers on two or three different days its strength would be only a fraction of the safe value.

When working in cramped or dirty situations such as narrow, heavily-timbered deep excavations in clay soil in wet weather, it is very difficult to fix reinforcement and impossible to keep it really clean. If practicable in such cases it is an advantage to substitute mass concrete construction for reinforced concrete. For mass concrete foundations only labourers and timberman are required, whereas reinforced concrete requires, in addition, steelfixers and carpenters and more supervision.

Chapter IV—PRINCIPLES OF REINFORCED-CONCRETE DESIGN

DESPITE its weather-resisting qualities, plain concrete as a structural material has a very limited application on account of its weakness in tension. In reinforced concrete this is remedied by adding steel bars at all points where tension develops. The concrete not only supplies the compressive strength, but encloses and protects the bars from the weather. Happily, the coefficient of expansion of steel is very closely the same as that for concrete, namely, ·000006 per degree F., and temperature changes, therefore, cause no internal stresses. Moreover, the concrete clings tightly to the surface of the bars, so that the whole structure expands, contracts, and deflects as one uniform whole without any slipping of the bars through the concrete.

Reinforcement. This is generally mild-steel round bars of commercial grade from $\frac{3}{16}$ in. to $1\frac{1}{2}$ in. diameter and up to 45 ft. in length. Larger and longer bars are only used in special cases. These bars are bent *cold* into various shapes so as to dispose them to the best advantage. They are then placed in the centering and the concrete is poured round them. Mild steel has a tensile breaking strength of 28 to 33 tons per square inch, a working stress of 16,000 to 18,000 lb. per square inch being usual. Its elastic modulus is 30,000,000 lb. per square inch (i.e. about fifteen times the elastic modulus of concrete).

Combined Properties. The structure deflects as a whole in conformity with the laws of elastic structures. As no slipping of the steel takes place, it follows that any steel bar shortens or lengthens by an amount exactly equal to the lengthening or shortening of the concrete which immediately surrounds it. For any given unit strain, the stress is equal to the strain multiplied by the elastic modulus. Since the modulus of steel is fifteen times the modulus of concrete, it follows that for any given strain the corresponding steel stress is fifteen times as great as the concrete stress. A strain of ·0001 would mean a stress of 3,000 lb. per square inch on the steel and only 200 lb. per square inch on the concrete.

Adhesion—Grip-length of Bars. A mild steel round bar with a block of concrete cast round it, as in Fig. 23, will resist efforts to pull it out, such resistance having a safe working value of 100 lb. per square inch of the surface of the bar in contact with the concrete. Now, this surface is $\pi \times$ (diam.) $\times$ (embedded length). The safe tension T on the bar is limited to 18,000 $\times$ area, which is 18,000 $\times \pi \times$ (diam.)^2 $\times \frac{1}{4}$ lb. To resist the full safe tension on the bar, the adhesion must, therefore, equal this last value.

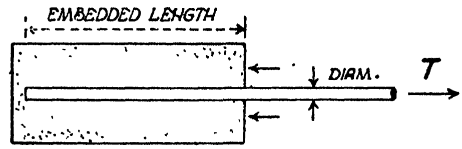


FIG. 23 ADHESION OF BAR

i.e. $\pi \times$ (diam.) $\times$ (embedded length) $\times$ 100

$$= 18{,}000 \times \pi \times (\text{diam.})^2 \times \tfrac{1}{4},$$

or the embedded length $= 45 \times$ (diam.).

Any bar, therefore, that has an embedded length, or *grip-length,* equal to or greater than 45 diameters, will safely carry the full allowable tension of 18,000 lb. per square inch without slipping. If the bar is stressed to 16,000 lb. per sq. in., the grip length must be 40 diameters.

WORKING STRESSES

In 1933 the Reinforced Concrete Structures Committee of the Building Research Board put forward a code. This has never been completely accepted, and various revised codes have been issued by other authorities. In the examples that follow, one set of stresses will be worked to as given below. The adoption of higher or lower stresses or other values of the elastic modulus cannot affect the principles and methods of design, although they may involve many tiresome changes in the coefficients used.

NON-WATERTIGHT CONCRETE, 1 : 2 : 4—

in compression in beams and slabs	750 lb. per sq. in.
in compression in columns .	600 lb. per sq. in.
in tension	nil

in beam shear . . . 75 lb. per sq. in.
in punching shear . . 150 lb. per sq. in.
in bond . . . . 100 lb. per sq. in.

WATERTIGHT CONCRETE, 1 : 1½ : 3 IN TANKS, ETC.

in compression . . . 850 lb. per sq. in.
in tension . . . . nil
in beam shear . . . 75 lb. per sq. in.
in punching shear . . 150 lb. per sq. in.
in bond . . . . 100 lb. per sq. in.

MILD STEEL TO B.S S.

in tension in circular tanks . 13,500 lb. per sq. in.
in tension in other watertight work . . . . . 16,000 lb. per sq. in.
in tension in other work . 18,000 lb. per sq. in
Ratio of elastic moduli $E_s : E_c$ 15 : 1.

Cover (measured to outside of bar) must never be less than the diameter of the bar and, in addition, should not be less than the following—

In floor and wall slabs not exposed . ½ in.
In floor and wall slabs exposed . . ¾ in.
Main bars in beams not exposed to weather . . . . . . 1 in.
Main bars in beams exposed to weather 1½ in.
Main bars in columns . . . . 1½ in.

NOTATION. Unfortunately, there is no notation for reinforced concrete which is in general use. In these articles the following symbols will be used (the units in which each will be stated are also given)—

A_s = area of tensile steel (sq. in.)
A'_s = area of compression steel (sq. in.)
B = width of flange in T-beams (in.)
b = breadth of rectangular beam sections (in.)
b' = breadth of rib in T-beams (in.)
d = effective depth (in.)
d' = depth of A'_s from compression edge (in.)
E_c = elastic modulus of concrete (lb. per sq. in.)
E_s = elastic modulus of steel (lb. per sq. in.)
F = total shear force (lb.)
f_c = maximum fibre stress on concrete (lb. per sq. in.)
f_s = stress on tensile stress (lb. per sq. in.)
f'_s = stress on compression steel (lb. per sq. in.)
I = moment of inertia (in.^{4}) in concrete units
j = fraction
jd = lever arm (in.)
L or l = span (ft.)
M = bending moment (lb.-in.)
$m = \dfrac{E_s}{E_c}$
n = fraction
nd = depth of neutral axis (in.)
p = percentage area of steel in column sections
p_s = percentage area of tensile steel in beams (on area bd)
p'_s = percentage area of compression steel in beams (on area bd)
$R = \dfrac{M}{bd^2}$ (for rectangular beam sections)
t = thickness of compression flange in T-beams (in.)
W = total load or point load (lb.)
w = distributed load (lb. per ft.-run)

Bending Moments in Continuous Beams. As reinforced-concrete structures are mostly monolithic, it follows that the beams, instead of consisting of isolated simply-supported spans as in steel-framed construction, are ***continuous*** throughout their whole length. (This condition must be clearly distinguished from the condition of *encastré*, or *fixed-ended*, beams. See the section on "Structural Engineering.") A load placed on one span affects the moments in the adjoining spans, and in order to find the maximum moment at a given point in any span, we must take the worst loading, not only on the span itself, but in all adjacent spans. For example, the loading in the upper part of Fig. 24 produces very different moments from the loading in the lower part of the same figure. The maximum moments may be worked out by the Theorem of Three Moments in any of its forms, but for beams of equal spans, carrying a uniform superload, we can take certain practical values to cover all cases, as follows—

TWO EQUAL SPANS

Positive moment in spans $+\dfrac{wL^2}{10}$

Reversed moment over centre support $-\dfrac{wL^2}{8}$

THREE OR MORE EQUAL SPANS

Positive moment in end span $+\dfrac{wL^2}{10}$

Positive moment in middle spans $+\dfrac{wL^2}{12}$

Reversed moment over next-to-end support $-\dfrac{wL^2}{10}$

Reversed moment over internal supports $-\dfrac{wL^2}{12}$

In all the above, w is the combined live and dead load per foot run. For point loads, calculate the moment as on a simply-supported beam and take two-thirds of this for internal spans and four-fifths for end spans. (See the example of floor design in Chapter VII.)

Shear on Continuous Beams. For two equal spans the shear near the central support is ⅝wL. For all other cases the shear may be reckoned as for a series of simply-supported beams. Shear reinforcement is described in Chapter V.

Rectangular Beam-sections Subjected to Bending Moment. Let Fig. 25 represent the cross section of a rectangular beam having an area of tensile steel A_s and an area of compression steel A'_s, subjected to a bending moment M. The width is b, and the depth from the compressed edge down to the centre of the tensile steel is d. The depth of the neutral

axis is expressed as nd. Below the neutral axis tension is developed and, as concrete cannot be relied on to resist tension, the area of concrete below the neutral axis is useless to resist bending moment stresses. For this reason we always measure the depth of a beam section down to the tensile steel (*not* the overall depth of the concrete). This value d is called the *effective depth.*

By the standard theory of flexure for elastic members, the unit *strain* of any fibre is directly proportional to its distance from the neutral axis. If the fibre stress on the extreme top layer of concrete is f_c, then the unit strain (compression) is $\frac{f_c}{E_c}$. The unit strain on the tensile steel is in the proportion of its distance from the neutral axis, namely,

$$\frac{(1-n)d}{nd} \times \frac{f_c}{E_c}$$

This strain would correspond to a steel stress

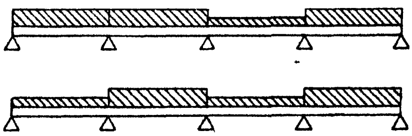


FIG. 24

$$f_s \text{ of } E_s \times \frac{(1-n)d}{nd} \times \frac{f_c}{E_c}$$

$$\text{i.e. } f_s = \frac{E_s}{E_c} \times \frac{(1-n)d}{nd} \cdot f_c$$

$$= m \cdot \frac{(1-n)d}{nd} \cdot f_c$$

$$\text{or } \frac{f_s}{m} = \frac{(1-n)d}{nd} \cdot f_c,$$

as indicated by the straight line in Fig. 25. The stress on the compression steel A'_s is similarly, by proportion,

$$f'_s = m \cdot \frac{(nd-d')}{nd} \cdot f_c$$

It must be remembered, however, that if we add 1 sq. in. of compression steel, we thereby displace 1 sq. in. of concrete. If the compression steel were not there, this square inch of concrete would carry

$$\frac{(nd-d')}{nd} \cdot f_c \text{ lb.}$$

Therefore the *net* addition to the strength of the section is

$$m \cdot \frac{(nd-d')}{nd} \cdot f_c - \frac{(nd-d)}{nd} \cdot f_c$$

$$= (m-1) \cdot \frac{(nd-d')}{nd} \cdot f_c \text{ per sq. in.}$$

Or we can say that the *effective* value of f'_s is

$$(m-1)\frac{(nd-d')}{nd} \cdot f_c$$

If we know the values of f_c and n, we can calculate the stresses at all points, and thence we can calculate the moment of resistance of the section. To write this down for the general case is very complicated, and to solve the problem the reverse way, that is, to find n and

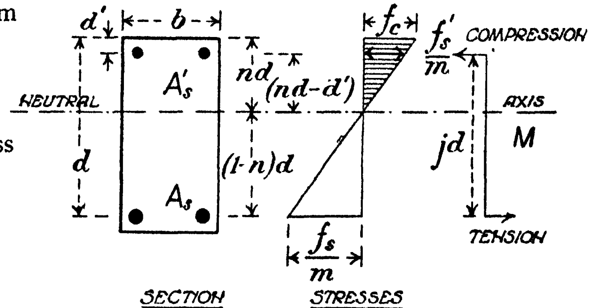


FIG. 25

f_c when M is given, is practically impossible. In practice, however, some of the proportions are very nearly constant, and we can, by making certain simple assumptions, construct a curve which will solve the problem for all practical cases. We shall confine ourselves to the value $m = 15$. The value $\frac{d'}{d}$ is always close to 0·1. The ratio A'_s to A_s varies between 0 and 1, and the bending strength varies uniformly with this ratio (very nearly).

Rectangular beam-sections seldom fail by excessive stresses in the steel, so that we shall express the strength in terms of f_c. An example will make the matter clearer.

In Fig. 25, assume $A'_s = \frac{1}{2} A_s$, $d' = 0{\cdot}1d$, $n = 0{\cdot}4$, and $m = 15$, and express the strength of the section in terms of f_c.

$$f_s = 15 \times \frac{0{\cdot}6}{0{\cdot}4} \times f_c = 22{\cdot}5 f_c$$

$$\text{Effective } f'_s = (15-1) \times \frac{0{\cdot}3}{0{\cdot}4} \times f_c = 10{\cdot}5 f_c$$

The stress on the concrete varies uniformly from f_c to zero.

Compressed area $= bnd = b \times 0{\cdot}4d$

Total compression on concrete

$$= \tfrac{1}{2} \times b \times 0{\cdot}4d \times f_c = 0{\cdot}2bdf_c$$

(Note that we do not deduct the area of A'_s, as we have already made an allowance for this by reducing the *actual* value of f'_s to the *effective* value.)

The centre of compression is $\tfrac{2}{3} \times 0{\cdot}4d = 0{\cdot}267d$ above the neutral axis.

Total effective compression on $A'_s = A'_s \times$ effective $f'_s = A'_s \times 10{\cdot}5\, f_c$, and the centre of this compression is $0{\cdot}3d$ above the neutral axis.

Total effective compression on A'_s

$$= \tfrac{1}{2} \cdot \frac{p_s \times bd}{100} \times 10{\cdot}5 f_c$$

Total tension on $A_s = \dfrac{p_s bd}{100} \times 22{\cdot}5 f_c$

These three must balance.

$$\therefore \frac{p_s bd}{100} \times 22{\cdot}5 f_c = 0{\cdot}2bdf_c + \tfrac{1}{2} \cdot \frac{p_s bd}{100} \times 10{\cdot}5 f_c$$

giving $p_s = 1{\cdot}16\%$.

The moment of resistance is the sum of the moments about the neutral axis, and must equal the applied moment M.

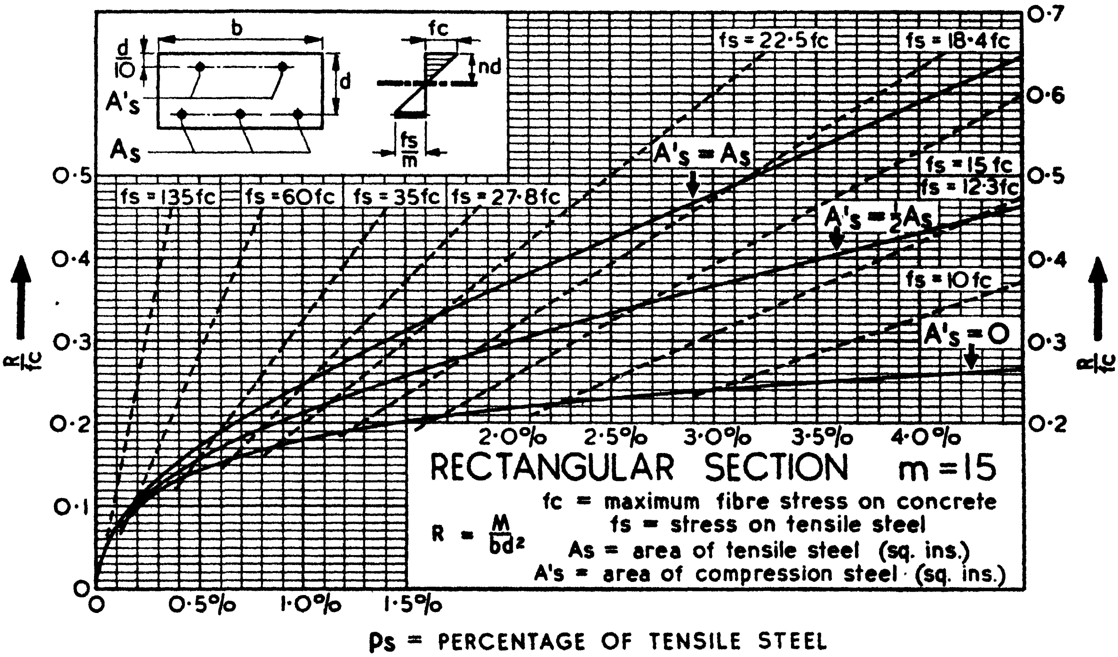


FIG. 26. BENDING STRENGTH OF RECTANGULAR BEAM-SECTIONS

Now, $A'_s = \dfrac{p'_s \times bd}{100}$ (by definition)

and $A'_s = \tfrac{1}{2} A_s$ (by assumption)

$$\therefore A'_s = \tfrac{1}{2} \cdot \frac{p_s \times bd}{100}$$

The total tension on the tensile steel is $A_s f_s$, which is

$$\frac{p_s bd}{100} \times 22{\cdot}5 f_c,$$

and this occurs $0{\cdot}6d$ below the neutral axis.

We have assumed that the section resists a pure bending moment, therefore the resultant of all the stresses is zero.

Total compression on concrete $= 0{\cdot}2bdf_c$

Moment of concrete compression

$$= 0{\cdot}2bdf_c \times 0{\cdot}267d = 0{\cdot}0534bd^2 f_c$$

Moment of stresses in A'_s

$$= \tfrac{1}{2} \times 1{\cdot}16 \times \frac{bd}{100} \times 10{\cdot}5 f_c \times 0{\cdot}3d = 0{\cdot}0183bd^2 f_c$$

Moment of stresses in A_s

$$= 1{\cdot}16 \times \frac{bd}{100} \times 22{\cdot}5 f_c \times 0{\cdot}6d \quad = 0{\cdot}1570bd^2 f_c$$

$$\overline{\quad 0{\cdot}2287bd^2 f_c \quad}$$

$$\therefore M = 0{\cdot}2287bd^2f_c$$

$$R = \frac{M}{bd^2} = 0{\cdot}2287f_c \text{ or } \frac{M}{bd^2f_c} = 0{\cdot}2287$$

If $f_c = 650$ lb. per sq. in.

$R = 149$

$M = 149bd^2$

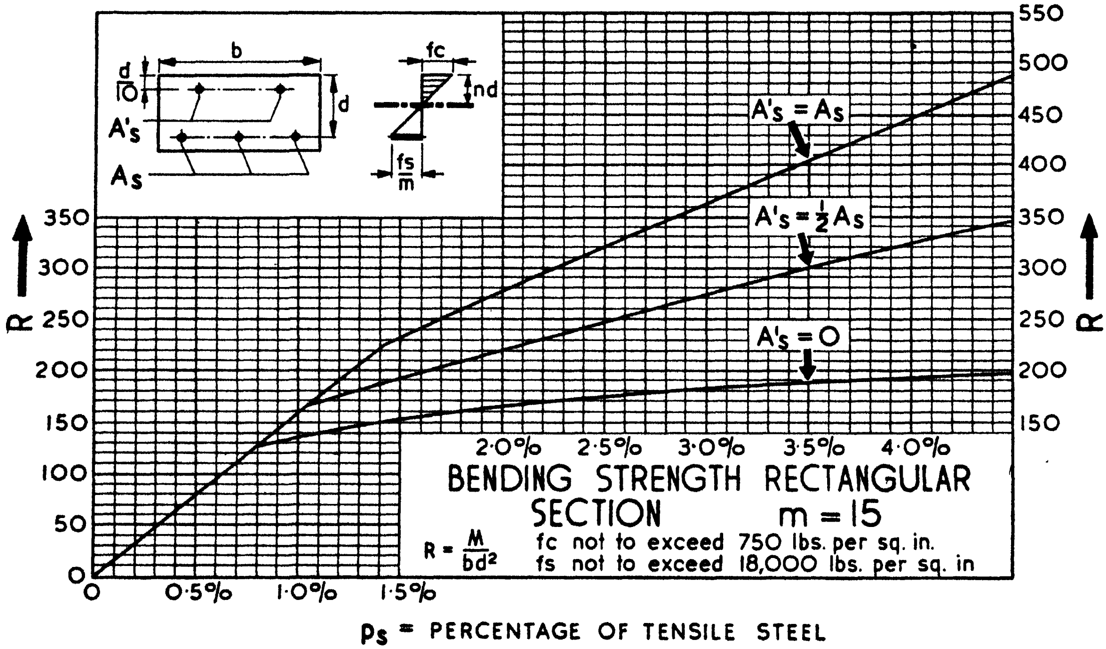


FIG. 26A. BENDING STRENGTH OF RECTANGULAR BEAM-SECTIONS

Fig. 26 may be used for any values of f_c and f_s so long as $m = 15$. Fig. 26A is much simpler, but may only be used when working to $f_c = 750$ and $f_s = 18{,}000$.

as $n = 0{\cdot}4$, $f_s = 22{\cdot}5f_c = 22{\cdot}5 \times 650$

$= 14{,}600$ lb. per square inch.

If we choose other values of n and other ratios of A'_s to A_s, then we can plot the whole of Fig. 26, which can be used to solve the problem either way.

Special Case — 126bd². When $A'_s = 0$, $f_c = 750$ lb. per square inch, and $f_s = 18{,}000$ lb. per square inch, then $n = 0{\cdot}384$, $jd = 0{\cdot}872d$, $p_s = 0{\cdot}80\%$, and $R = 126$. The safe moment of resistance is, therefore, $126bd^2$. (As b and d are expressed in inches, then $126bd^2$ lb.-in. is the moment of resistance.) These particulars may be memorized, as they are used for designing practically all sections of floor-slabs and wall-slabs when working to 750 and 18,000 lb. per sq. in.

EXAMPLE. A lintel is 12 in. deep and 14 in. wide and reinforced as shown in Fig. 27. It carries a moment of 250,000 lb.-in. What stresses will this produce in the concrete and steel?

SOLUTION.

$d = 10{\cdot}5$ in.

$bd = 14 \times 10{\cdot}5 = 147$

$bd^2 = 14 \times 10{\cdot}5^2 = 1550$

$A'_s = A_s = 1{\cdot}76$ sq. in. $= 1{\cdot}2\%$

From Fig. 26,

$$\frac{M}{bd^2f_c} = 0{\cdot}272 \text{ and } f_s = 26f$$

$$\therefore \frac{250{,}000}{1550f_c} = 0{\cdot}272$$

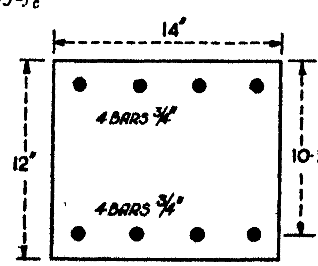


FIG. 27

giving $f_c = 594$ lb. per sq. in. and $f_s = 15{,}400$ lb. per sq. in.

The length of bars and number of stirrups for such a case are discussed in Chapters V and VII.

Chapter V—REINFORCED CONCRETE FLOORS

Sections of Floor Slabs and Wall Slabs to Resist Bending Moments. Under present conditions and prices in this country, it is found best to design for a value of $R = 126bd^2$, using tensile steel only. The overall thickness for a floor slab should be not less than 4 in. For a light wall slab 4 in. is sufficient, but for the wall of a bunker, etc., having heavy reinforcement both sides, then 4½ in. is the minimum desirable. The overall thickness is usually made an integral number of half inches, i.e. 4 in., 4½ in., 5 in., 5½ in., 6 in., etc. The reinforcement most

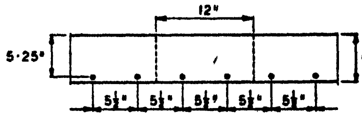


Fig. 28

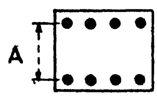


Fig. 29

suitable for a 4 in. slab is ⅜ in. round bars; for a 6 in. slab, ½ in. round bars; for 8 in., 10 in., and 12 in. slabs, ⅝ in., ¾ in., and 1 in. bars respectively. The bars should be spaced not wider apart than four times the effective depth of the slab.

Example. A section of a floor slab 12 in. wide has to resist a moment of 36,000 lb.-in. Using stresses of 750 and 18,000 lb. per sq. in., design a suitable section.

Solution.

$$R = \frac{M}{bd^2} = \frac{36{,}000}{12 \text{ in.} \times d^2} = 126$$

$$\therefore \text{ Minimum } d = \sqrt{\frac{36{,}000}{12 \times 126}} = 4{\cdot}88 \text{ in.}$$

Use a 6 in. slab with ½ in. bars and ½ in. cover giving $d = 6 \text{ in.} - \tfrac{1}{4} \text{ in.} - \tfrac{1}{2} \text{ in.} = 5{\cdot}25 \text{ in.}$

Lever arm $= 0{\cdot}872d$ (very nearly)

$$A_s = \frac{36{,}000}{18{,}000 \times 0{\cdot}872 \times 5{\cdot}25 \text{ in.}} = 0{\cdot}435 \text{ sq. in.}$$

If we used ½ in. bars, spaced every 5½ in. in the floor, then we should have an average of 0·43 sq. in. for every 12 in. width of cross-section.

Therefore a 6 in. slab with ½ in. bars spaced 5½ in. centres would be suitable, as shown in Fig. 28.

Sections of Slabs and Beams: Steel-beam Theory. It has been put forward that a section as shown in Fig. 29, having equal areas of reinforcement top and bottom, could be regarded as a steel beam (the concrete being neglected) working to stresses of 18,000 lb. per sq. in. in tension and compression. For beams with large percentages of steel, this theory is on the unsafe side, and it should only be used with

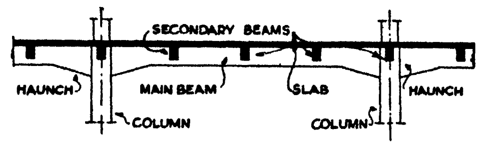


Fig. 30

caution by experienced designers. Beginners should always use the values in Fig. 26.

T-Section Beams

T-Beam sections occur in what are known as slab-and-girder floors. Fig. 30 shows a section through such a floor. The *floor-slab* spans from one *secondary beam* to another in the same way as the floorboards in a timber floor span from joist to joist. The secondary beams span from *main beam* to main beam as the joists

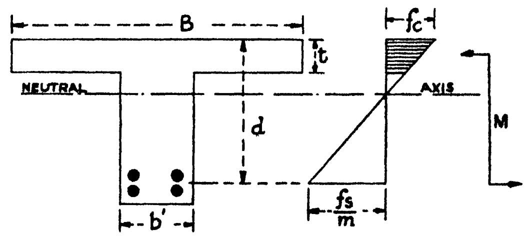


Fig. 31

in a timber floor span from bearer to bearer. The main beams span from column to column.

Now, such a floor is cast all in one piece. The floor slab not only serves as planking, but is also an integral part of the secondary beams and main beams. These beams have, therefore, a T-section as shown in Fig. 31.

The question at once arises: How much of the floor slab can we reckon on to furnish the flange, that is, what is the limiting value of B? Practice indicates that the following values are safe—

I. *For T-Beams, B shall not exceed—*

1. One-third of the span.

2. The spacing of beams centre to centre.
3. (Twelve times the slab thickness) + (rib thickness), that is $12t + b'$.

II. *For L-Beams, B shall not exceed—*

1. One-sixth the span.
2. Rib thickness plus half clear spacing.
3. Rib thickness plus four times slab thickness.

The above values are only safe if steel reinforcement in the floor slab runs right across the whole width B.

Design—SPECIAL CASE. It sometimes happens, though very rarely, that the value of t in Fig. 31 is so great compared with d that the neutral axis falls inside the flange. In this case, the section has exactly the same bending strength as a rectangular section of breadth B and effective depth d.

USUAL CASE. The best way to design such sections is as follows—

1. Determine the maximum moment M that the section has to resist.

2. Choose a preliminary section having the width of the projecting portion b' about half the depth of the projection, and such that $b' \times (projection)^2 \times 450 = M$.

$$\text{i.e.} \quad b' \times (2b')^2 \times 450 = M$$

$$\text{or} \quad b' = \sqrt[3]{\frac{M}{1800}}$$

The reason for this is that most practical T-sections can resist moments of 250 $b'd^2$ to 600 $b'd^2$, an average value being 450 $b'd^2$. The depth of the projection is very nearly equal to the effective depth. (Remember that a 9 in. × 18 in. net beam will resist a moment of about 1,000,000 lb.-in. if reinforced with four bars 1 in. diameter and provided with a 4 in. flange 25 in. or more wide.)

3. Assume that $f_c = 750$ and $f_s = 18{,}000$ lb. per sq. in., giving $n = 0{\cdot}384$. We can then easily calculate the average compressive stress on the flange.

4. Estimate the lever arm jd. The centre of compression is very nearly in the centre of the depth of the flange t. The centre of gravity of the bars for small, medium, and large beams is about $1\frac{1}{2}$ in., $2\frac{1}{2}$ in., or $3\frac{1}{2}$ in., respectively, up from the bottom edge. A little practice enables the designer to estimate the lever arm very closely.

5. Divide the moment M by the lever arm jd, thus finding the total compression and the total tension. We already know the average stress on the compression flange, and the value of t is fixed by the design of the floor slab before we commence to design the beams. We can therefore determine what width of flange B is required. If the permissible width is not sufficient, then an area of compression steel may be introduced, but it must be remembered that all the compression steel must lie within a width b' and be tied by links to the tensile steel; also, that heavy compression is, as a rule, only found in main beams, and the compression bars must be kept low enough to

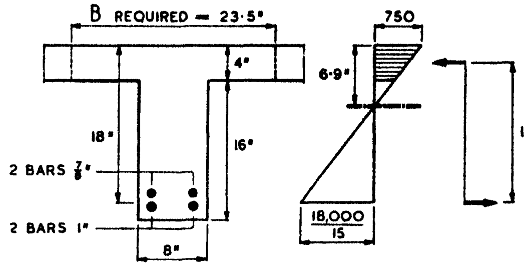


FIG. 32

allow the bars in the secondary beams to pass over them. This brings them down near the neutral axis and reduces their value. It follows that, in practice, not very much help can be looked for from compression steel, and it is necessary either to use richer concrete, increasing the value of f_c, or to increase the depth of the beam to lessen the total compression, or sometimes to redesign the whole floor, using a thicker slab.

If compression steel is used, the effective value of f'_s is easily found by proportion, as we know the value of nd. An area A'_s is then found to supply all the compression in excess of what the concrete flange will safely take.

6. Before final adoption the section should be checked for shear as described later.

EXAMPLE. **A T-section has a 4 in. flange and has to resist a moment of 800,000 lb.-in. The maximum allowable width of B is 48 in. Find a suitable section.**

SOLUTION.

$$\text{Say, } b' = \sqrt[3]{\frac{800{,}000}{1800}} = \sqrt[3]{445} = 7{\cdot}62 \text{ in}$$

Try a section 8 in. × 16 in. net as shown in Fig. 32.

The effective depth will be about 18 in., and the lever arm jd about 16 in.

Depth of neutral axis = $0{\cdot}384 \times 18$ in. = 6·9 in.

Average compression on flange occurs 2 in. from top.

i.e. 4·9 in. from the neutral axis and is $\frac{4 \cdot 9}{6 \cdot 9} \times 750 =$ 532 lb. per sq. in.

For every 1 in. width of B the flange takes 4 in. $\times$ 532 $\times$ 1 in. = 2140 lb.

$$\text{Total compression} = \text{total tension} = \frac{800{,}000}{16\text{ in.}} = 50{,}000\text{ lb.}$$

$$\text{This would require } B = \frac{50{,}000}{2140} = 23 \cdot 5 \text{ in. only.}$$

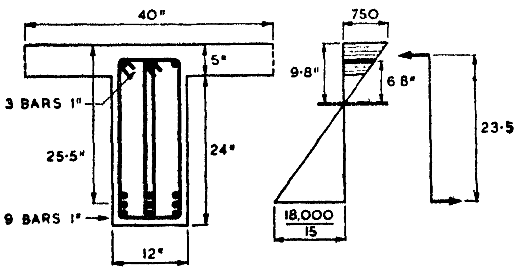


FIG 33

As we are allowed any width up to 48 in, we are very much on the safe side.

$$A_s = \frac{\text{total tension}}{18{,}000} = \frac{50{,}000}{18{,}000} = 2 \cdot 78 \text{ sq. in.}$$

This may be made up of 2 bars 1 in. = 1 57 sq. in.
plus 2 bars $\frac{7}{8}$ in. = 1·20 sq. in.

2·77 sq. in.

Or we may use 4 bars 1 in. diameter and reduce the size of the beam to 8 in. $\times$ 14 in.

EXAMPLE. A **T**-section has a 5 in. flange and has to resist a moment of 3,000,000 lb.-in. Owing to the occurrence of holes in the floor slab, only 40 in. width of flange can be reckoned on. Find a suitable section.

SOLUTION. M = 3,000,000 lb.-in.

$$\text{say } b' = \sqrt[3]{\frac{3{,}000{,}000}{1800}} = \sqrt[3]{1{,}670} \text{ in.} = 11 \cdot 85$$

say 12 in. $\times$ 24 in. net section as in Fig. 33.
The effective depth is about 25·5 in.
Depth of neutral axis = 0·384 $\times$ 25·5 = 9 8 in.
Average compression on flange occurs 2·5 in. down

$$= \frac{7 \cdot 3}{9 \cdot 8} \times 750 = 560 \text{ lb. per sq. in.}$$

Every 1 in. width of B takes 1 in. $\times$ 5 in. $\times$ 560 = 2,800 lb.
Lever arm, say, 23·5 in.
Total compression = total tension

$$= \frac{3{,}000{,}000}{23 \cdot 5 \text{ in.}} = 127{,}000 \text{ lb.}$$

This would require a width of flange of $\frac{127{,}000}{2{,}800}$ or 44 in., but we have only 40 in. maximum

Total compression	=	127,000 lb.
Available flange will take 40 $\times$ 2,800	=	112,000 lb.
Excess	=	15,000 lb.

In such a beam the compression steel would probably have to be at least 3 in down as shown, i.e. 6·8 in. above the neutral axis.

$$\text{Effective value of } f'_s = \frac{6 \cdot 8}{9 \cdot 8} \times 750 \times 14$$

$$= 7{,}300 \text{ lb. per sq. in.}$$

Area of compression steel A'_s required

$$= \frac{15{,}000}{7{,}300} = 2 \cdot 07 \text{ sq. in.}$$

3 bars 1 in. = 2·35 sq. in.

$$A_s = \frac{127{,}000}{18{,}000} = 7 \cdot 05 \text{ sq. in}$$

9 bars 1 in = 7·05 sq. in.

It must be remembered that every practical case has its own special considerations. Sometimes we have to modify a design because of limited headroom, heavy shear forces, necessity of making beams all one size to save centering, provision for " inserts " in beams, modifications to allow for bars overlapping, etc.

SHEAR STRENGTH

Beams and Slabs. In a steel or timber beam the maximum intensity of shear stress occurs at the neutral axis. In a reinforced-concrete

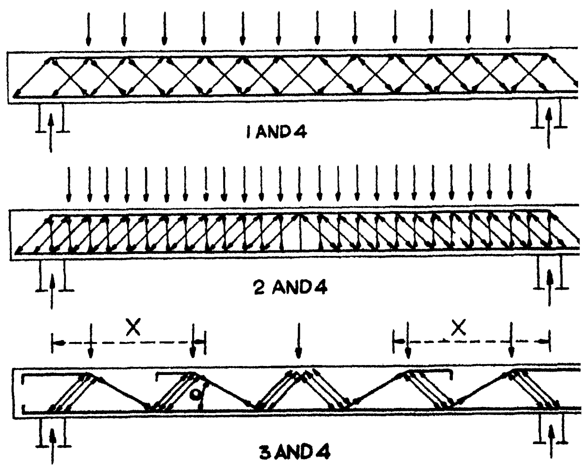


FIG. 34

beam the only active area on the tension side of the beam is the tensile steel, and the intensity of shear in a rectangular section is constant below the neutral axis. The "shear area" is *bjd*, that is, the breadth multiplied by the lever arm. The maximum intensity of shear stress is the total shear divided by the *bjd* area. For a T-section we must take the

smallest width of the beam below the neutral axis; this is the width of the rib b', the shear area being $b'jd$.

Floor Slabs. For floor slabs which have no bent-up bars, a safe shear resistance of 75 bjd may be taken for standard 1 : 2 : 4 concrete. For floor slabs where half the main tensile steel is bent up and carried over the supports, a value

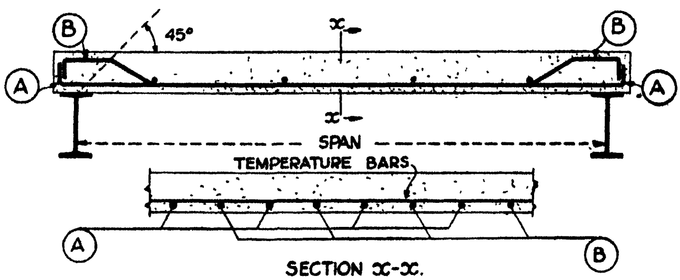


FIG. 35

of 100 bjd may be taken. The shear stress on floor slabs is, as a rule, very low.

T-Beams. There is no really logical method of expressing the shear strength of a practical beam, but it may be regarded as depending on four items—

1. Diagonal shear tension in the concrete combined with item (4).
2. Tension in vertical stirrups combined with item (4).
3. Tension in inclined bars combined with item (4).
4. An inclined compression in the concrete corresponding to all the above tensions.

All these are shown diagrammatically in Fig. 34.

1. The value of this is 75 $b'jd$ lb.

2. If the stirrups are well anchored round main bars top and bottom, they may be stressed to 18,000 lb. per sq. in. If only anchored at one end they may be stressed to 12,000 lb. per sq. in. If spaced not farther apart than $\frac{1}{2}jd$, the strength of a system of vertical stirrups is

$$18{,}000 \times \frac{jd}{12} \times \text{(area of stirrups cut by 1 ft. run of neutral axis).}$$

In this formula jd is the lever arm in inches. A similar system of stirrups with the same horizontal spacing but inclined at 45° would have a strength of $\sqrt{2}$ times this value. Stirrups spaced farther apart than $\frac{1}{2}jd$ allow shear cracks to form between them and are therefore ineffective. Whatever the calculations may show, light beams should always have a few light stirrups to tie the steel together, spaced not farther apart than jd. Heavy beams should have an area per foot run of neutral axis of at least $\frac{480\,b'}{18{,}000}$ sq. in. spaced not farther than $\frac{1}{2}jd$ near the supports.

3. The shear strength of a bar inclined at an angle θ to the neutral axis is 18,000 × (sin θ) × (area of bar) if it is provided with a grip-length of 45 diameters after crossing the neutral axis. The diagram in Fig. 34 shows two bars, one following the other, but often the shear force falls off near the centre of the span sufficiently to omit the middle bar. A single bar may be looked on as effective over a length X if placed as shown. For shallow beams θ should not exceed 30°, for deep beams (one-twelfth of the span or over) 45°, and very deep beams (one-third the span) 60°. Special inclined bars to take the shear are very seldom supplied, as it is generally possible to bend up some of the main tensile reinforcement where the maximum shear occurs.

4. It might be expected that a value of 750 lb. per sq. in. could be used for the inclined compression, but owing to the difficulty of

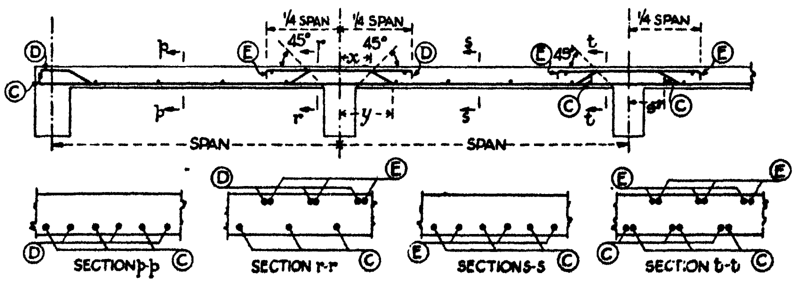


FIG. 36

satisfactorily transferring the inclined tension from the steel to inclined compression on the concrete, and also owing to heavy local shear forces where the bars change direction, a much lower value must be used. This compression limits the total shear force on the section, no matter what steel reinforcement is supplied, as follows—

(*a*) Shallow beams whose depth is less than one-twelfth of the span, 225 lb. per sq. in. on the $b'jd$ area.

(*b*) Deep beams whose depth is greater than one-twelfth of the span, 300 lb. per sq. in. on the $b'jd$ area.

(*c*) Very deep beams whose depth is greater than one-sixth of the span, 350 lb. per sq. in. on the $b'jd$ area.

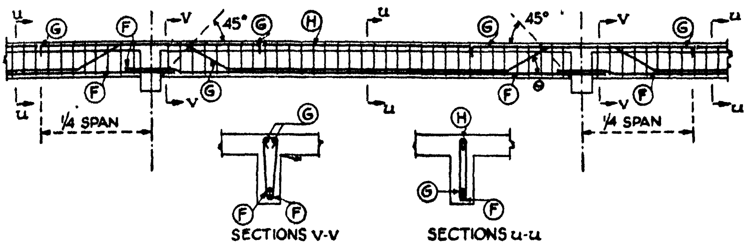


FIG. 37

The method of designing a T-beam for shear is therefore—

I. Make the $b'jd$ area at least sufficient to take the total shear at the worst section at 225 lb. per sq. in.

II. Arrange the main tensile bars to assist the shear strength of the beam to the best advantage. These, if carefully arranged, generally give a strength of about 100 $b'jd$.

III. Calculate the shear strength of the concrete alone at 75 $b'jd$. If this is not sufficient to carry the whole shear, then it may be assumed that the concrete has cracked in tension and that diagonal tension in the concrete cannot be relied on. The whole tension must therefore be taken on the steel. Calculate the shear strength of the bent-up bars and add stirrups to take the remainder, never providing less than the amount specified in paragraph (2) above.

Arrangement of Steel Reinforcement

Floor Slabs. A typical arrangement of steel bars for a single span is shown in Fig. 35. The reinforcement consists of steel bars *A* and steel bars *B* placed alternately. In addition to the main steel, which has to resist the calculated bending moment, ***temperature bars***, or distributors, are always supplied, running at right angles to the main reinforcement. For a 4 in. slab, $\frac{3}{8}$ in. bars spaced at 18 in. centres are sufficient; for a 6 in. slab, $\frac{3}{8}$ in. bars spaced at 12 in.; and so on in proportion to the thickness.

A typical standard arrangement for many spans is shown in Fig. 36. The bottom bars *C* may be made to run across two spans as shown. To resist the positive moment, the end span is reinforced with bars *C* and bars *D* alternately, while the middle span has bars *C* and *E* alternately. For reversed moment, the next-to-the-end support has bars *D* and *E* alternately, and bars *C* in compression; while the internal support has two bars *E*, one from either side, and either one bar *C* or two bars *C* in compression. If the bent-up bars are to be effective in shear, they should lie as shown with regard to the 45° line. The distance x must not be less than about one-tenth of the span, while distance y must not exceed about one-sixth of the span for continuous spans.

Secondary T-Beams. For a light secondary beam a typical arrangement is shown in Fig. 37. Sizes of projection varying from 4 in. × 8 in. to 6 in. × 14 in. may be used to resist moments of 70,000 lb.-in. to 550,000 lb.-in., the reinforcement varying from 2 bars $\frac{5}{8}$ in. to 2 bars $1\frac{1}{8}$ in.

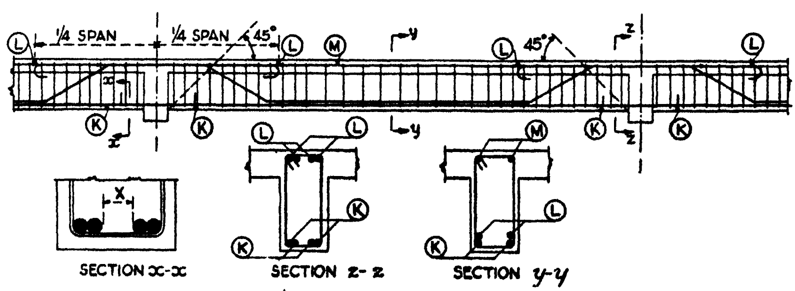


FIG. 38

The shear strength will vary from 6,000 lb. to 17,000 lb. To resist the positive moment at mid-span, we have bar *F* plus bar *G*; while to resist the reversed moment we have two bars *G*, one from either beam, and two bars *F* in compression. Secondary beams are seldom or never provided with splays or haunches, and most designers rely on the steel-beam theory when calculating the bending strength to resist reversed moment. Bars *F* and *G* are usually made the same diameter, which arrangement

(if we accept the steel-beam theory) automatically provides the same moment of resistance against reversed moment over the supports as against positive moment at mid-span. Since most secondary beams carry moments of $+\frac{wL^2}{12}$ and $-\frac{wL^2}{12}$ or $+\frac{wL^2}{10}$ and $-\frac{wL^2}{10}$, this steel arrangement is satisfactory. Bar G bent up at an angle θ of about 30° assists the shear strength near the supports. A small bar H is provided to support and anchor the top end of the stirrups and is not meant to function as compression steel.

For heavy secondary beams, the arrangement in Fig. 38 may be followed. This is very similar to two beams, as in Fig. 37, placed side by side. The two bottom bars K are cranked inward where they overlap at the supports, and the beam must be made sufficiently wide to allow at least 2 in. for the dimension marked "X." Such beams may vary from 8 in. × 14 in. net to 10 in. × 20 in. net to resist moments from 400,000 lb.-in. to 1,500,000 lb.-in. and shears from 20,000 to 40,000 lb., being reinforced with four bars ⅝ in. to four bars 1¼ in. diameter.

Stirrups for secondaries may be $\frac{3}{16}$ in. bars, ¼ in. bars, or ⅜ in. bars, for light, medium, and heavy secondary beams, respectively.

In both cases the bent-up bars are taken past the supports for a distance equal to one-quarter of the span. The bottom bars must be taken about 20 bar diameters past the supports.

Main T-beams : A light main beam may be made of the same section as a heavy secondary beam (see Fig. 38). For heavier sections, which usually have a higher percentage of steel, the beam should be splayed out by means of *haunches*, or *brackets*, at the columns. A typical heavy main beam is shown in Fig. 39. There are, however, many alternative arrangements. The main strength of a beam lies in long bars bent up at small slopes. Short bars, abrupt changes of reinforcement, and steep bends of heavy bars are to be avoided. Where bars overlap at the supports the distance marked X should be not less than 2 in.

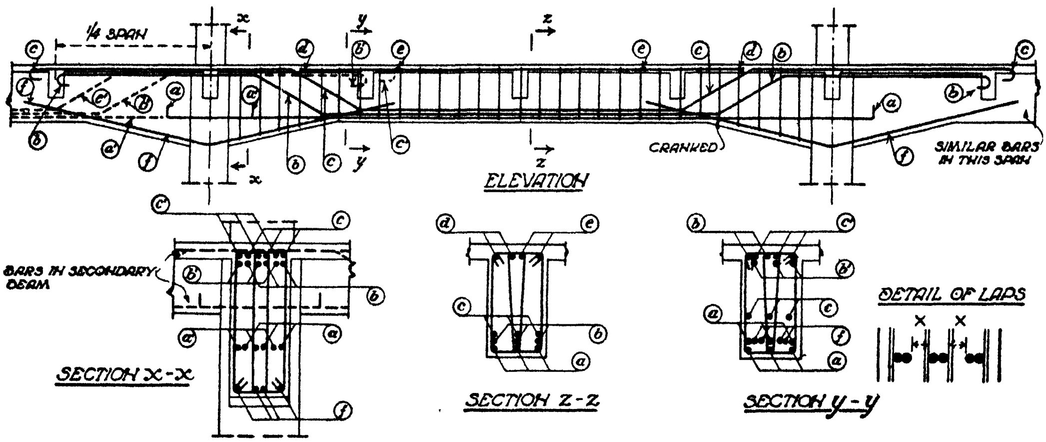


FIG. 39

It is impossible to discuss all the various bar arrangements, and the beginner should study very carefully all the details he sees. The loading consists usually of a series of point loads from the secondary beams, and the position of the secondaries should be taken into account when deciding on the position of the main bent-up bars.

General. In a continuous beam the moments are affected by the loading in adjacent spans. To cover all cases, the reinforcement should be sufficient to satisfy the values in Fig. 40. The bottom steel must satisfy the positive moments at all points, and the top steel must cover the negative moments over the support. Only bars having a grip-length of 45 diameters can take the full stress of 18,000 lb. per sq. in. If they are provided with a hook at the end, they can be relied on to resist 8,000 lb. per sq. in. 20 diameters from the end, and 4,000 lb. and 12,000 lb. per sq. in. at 10 and 30 diameters from the end. A bar bent up at a small slope will help to resist bending moment in a varying degree until it crosses the neutral axis. If in doubt about the strength of a bar arrangement,

the moment of resistance of the beam may be calculated at different points and plotted.

For example, suppose we have a continuous beam reinforced with two equal bars each of area A, as in Fig. 41. The lever arm will be practically constant. At mid-span the tensile steel is $2A$, and the positive moment of resistance is $2Ajd \times 18{,}000$. At section 1–1 one bar bends up and the positive moment of resistance starts to fall. At 2–2 only one bar is effective, the positive moment of resistance being $Ajd \times 18{,}000$. Nearer the support, at section 3–3, the bar has about 45 diameters' grip. However, as we proceed to the left again, the bar from the next span starts to function. Over the support we have $2A$ top steel, giving a moment of resistance of $2Ajd \times 18{,}000$. At section 4–4 one bar bends down. The remaining bar is fully effective up to section 5–5, from which point the allowable stress falls off to zero. The moment of resistance of this beam is drawn in the figure, and is compared with the covering moments for a distributed load given in Fig. 40.

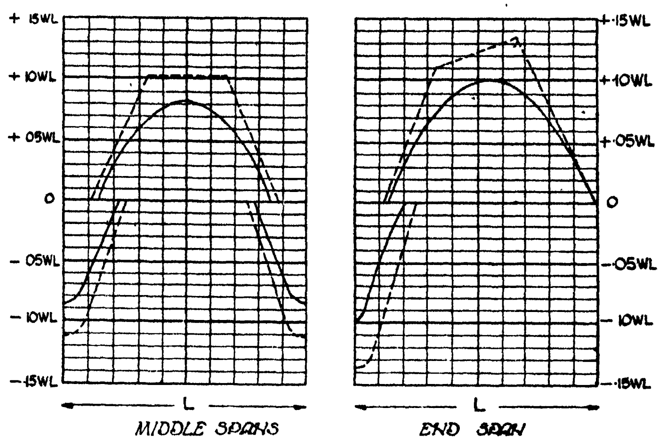


FIG. 40 COVERING MOMENTS FOR CONTINUOUS BEAMS

Dotted lines are for third-point loading. Full lines are for a uniformly distributed load. W is the total load on one span.

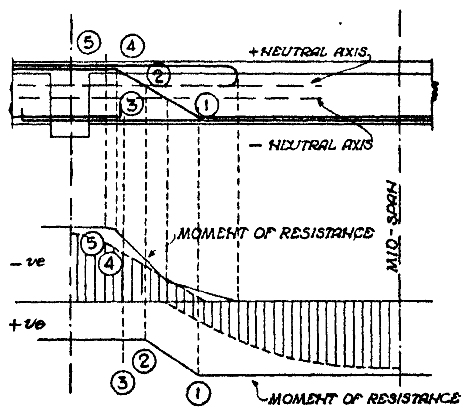


FIG. 41

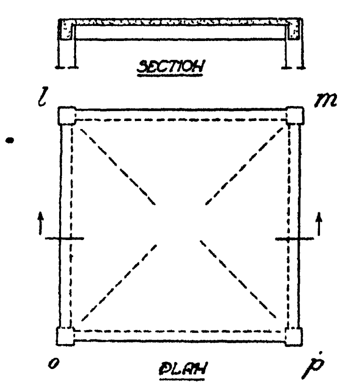


FIG. 42

Rectangular Beams: Rectangular beams, as a rule, have compression steel at mid-span where the maximum moments occur, but this need not be continued right across the span. It will be seen from Figs. 37, 38, and 39 that T-beams have light bars in the top to carry the tops of the stirrups. For rectangular beams a similar steel arrangement may be followed, if the diameter

of the top bars is made sufficient to provide the necessary area of top steel.

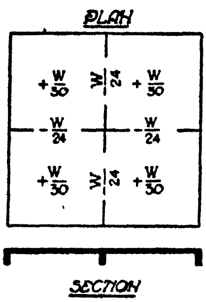
Square Panel (or Mesh Panel) Floor Slabs.

When a panel of floor slab is square or approximately square, as in Fig. 42, it may be supported by beams on all four sides. The strength of such a panel is very difficult to calculate by exact mathematics.

Some writers (as Grashof and Rankine) have treated the problem as two slabs, one spanning from *lo* to *mp* and the other from *lm* to *op*. In this case, the bending moments are calculated separately, the slab being made deep enough at $126bd^2$ to resist the greater moment. The steel bars running in each direction are then calculated separately.

The method of designing mesh panel slabs in the new Code follows these old-fashioned ideas, and the reader may refer to it as he may be compelled to work to it.

A more correct view is to treat the panel as a whole; take a coefficient to represent the maximum moments which occur across the diagonals (shown dotted in Fig. 42), and supply two equal rows of bars running in both directions. A slab which has equal reinforcement running in two directions at right angles can resist a bending moment in any direction. Mesh panels should not be used if one side is more than 1·5 times the other. For an isolated panel, simply supported on all sides, a moment of $\frac{W}{24}$ lb. ft. per foot run of cross-section should be allowed for, where W is the *total* load on the



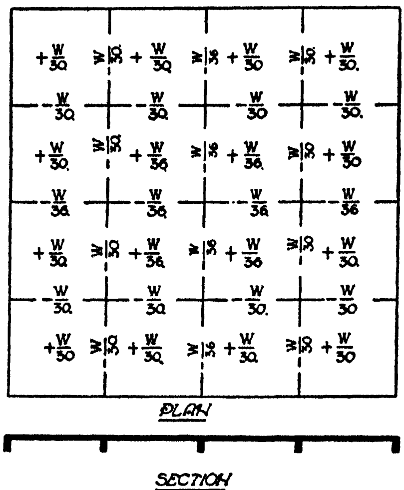


Fig. 43

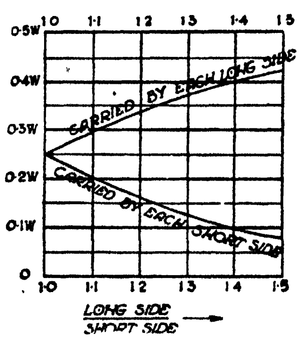


Fig. 44

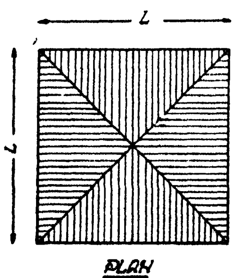


Fig. 45

panel in pounds. For continuous panels all of the same size, the moments given in Fig. 43 may be worked to. (These are in accordance with more modern ideas and not in accordance with the Code.) The bars running in one direction must lie on top of the bars in the other direction, more uniform. Care, however, should be taken to provide fairly deep beams, as excessive deflection will increase the moments in the panels.

EXAMPLE. A floor carries a superload of 200 lb. per sq. ft. and a timber floor-finish weighing 20 lb. per sq. ft. It is constructed in a large number of continuous mesh

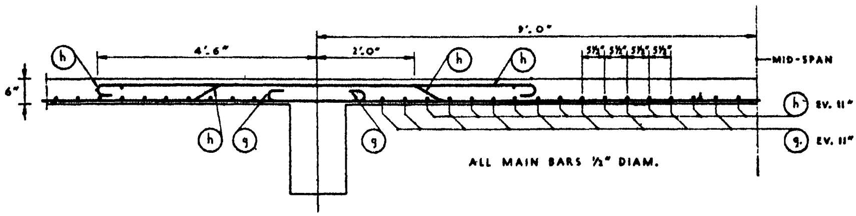


FIG. 46

but we may take d as the average depth of the two layers. Mesh panel roofs should not be thinner than 4 in. and floors not thinner than 5 in.

The total amount of load carried by each one of the supporting beams is shown by Fig. 44.

The intensity of loading on the supporting

panels, each 18 ft. × 18 ft. Design one interior panel, using the rational method.

SOLUTION.

Load per square foot = 200 lb. superload
20 lb. finish
75 lb. self-weight (say)
295 lb. total

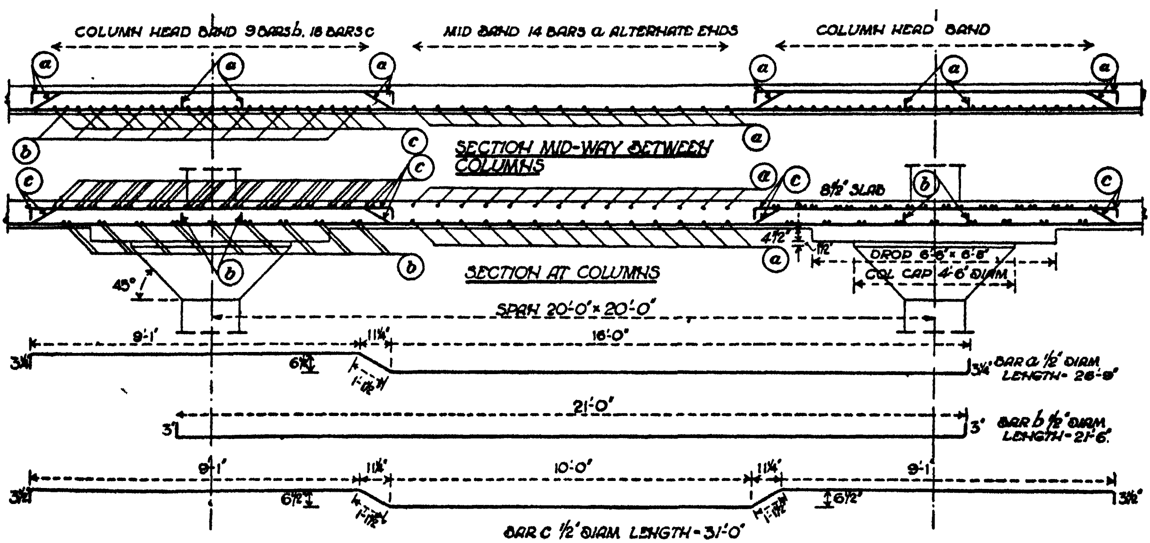


FIG. 47

beams is not uniform. For a single isolated square panel, the loading is approximately triangular, as indicated in Fig. 45.

Each beam supports a load of $\frac{W}{4}$, and is designed for a moment of $\frac{W}{4} \times \frac{L}{6}$ plus a moment due to its own self-weight of $\frac{wL^2}{8}$. For continuous panels the loading on the beams is much

$$W = 18 \times 18 \times 295 = 95{,}200 \text{ lb.}$$

$$M = \frac{W}{36} \text{ lb. ft. per foot of section}$$

$$= \frac{95{,}200}{36} \times 12 = 31{,}800 \text{ lb.-in.}$$

$$\text{Minimum } d = \sqrt{\frac{31{,}800}{126 \times 12}} = 4{\cdot}58 \text{ in.}$$

Use a 6 in. slab with ½ in. bars; average d = 5 in.

$$A_s = \frac{31{,}800}{18{,}000 \times {\cdot}872 \times 5 \text{ in.}} = 0{\cdot}405 \text{ sq. in. both ways}$$

½ in. bars at 5½ in. centres = 0·429 sq. in.

The slab is shown in Fig. 46.

Flat-slab Floors

The construction of flat-slab floors has been developed, largely by means of experiments, in America. It consists of a slab supported on columns which have a flared-out mushroom head, called a *column capital.* It is essential for successful application of this type of construction that the panels of floor are very nearly square, and that there are a large number of continuous panels. The heaviest moments are the reversed moments over the column capital in both directions, and to resist these it is most economical to thicken out the slab by providing a *drop-panel.* It should be noted that, in flat-slab design, the column is called upon to take a bending moment when the floor is unevenly loaded.

The large amount of experimental work which has been done on the subject makes the design of such floors an easy matter. All that the designer has to do is to turn up one of the standard series of flat-slab regulations[1] and follow these through, paragraph by paragraph. Before finally deciding on a slab thickness for the interior panels, it is advisable to check through the moments in the outer panels, as it looks better, if possible, to make them all the same thickness. This can sometimes be accomplished, when spacing out the columns, by making the internal panels slightly larger than the outside ones. Fig. 47 shows a typical interior panel for a floor 20 ft. by 20 ft. span carrying a super-load of 224 lb. per sq. ft., reinforced with a two-way system of bars. This needs an $8\frac{1}{2}$ in. slab and a drop panel of $4\frac{1}{2}$ in. extra. The different shapes of bar required are drawn in the figure.

Hollow-tile Floors

Floors in steel-framed office buildings are often called on to span 12 ft. or 15 ft. under a superload of 100 lb. per sq. ft. To save the weight and cost of a solid concrete slab, hollow-tile construction is often used. The tiles are usually of terra-cotta, 4 in. to 12 in. high, with walls of $\frac{1}{2}$ in. to $\frac{3}{4}$ in. thickness, according to size. If the exact weight of a tile is not known, it may be calculated by assuming that the material weighs 120 lb. per cub. ft. A 10 in. by 10 in. tile 6 in. high weighs about 25 lb. Typical sections of hollow-tile construction are shown in Fig. 48. The left-hand detail is suitable for mansard slopes, etc The centre detail is for a light floor, and the right-hand detail for a long-span floor. For floor work, the amount of concrete over the crown of the tiles should not be less than 1 in., and preferably not less than $1\frac{1}{2}$ in. The floor is designed as a series of small T-beams, the thickness of the compression flange being equal to the thickness of concrete plus $\frac{1}{2}$ in. allowance for the tile. The shear strength of each T-beam must be carefully checked.

There are very many patent hollow-tile floors on the market whose properties, prices, etc., may be obtained from the proprietors.

Some hollow-tile floors are divided into square panels which, by the use of tiles with closed ends, have concrete ribs running both ways. Such panels must NOT be designed for the bending moments in Fig. 43. They must be considered as two separate systems of beams, each carrying a proportion of the total load. The amount taken by each system may be calculated from Fig. 44.

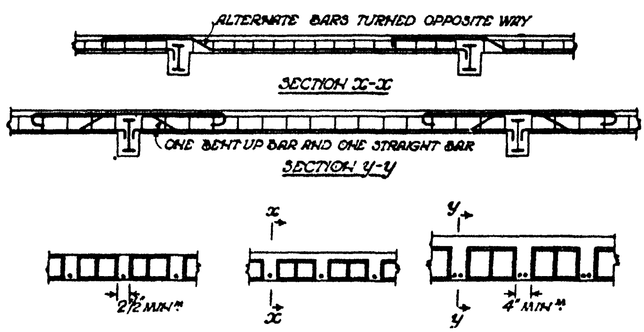


Fig. 48

Example. A hollow-tile floor carries a superload of 75 lb. per sq. ft. and a timber floor weighing 15 lb. per sq. ft. Design an interior bay spanning 17 ft.

Solution.

Load per square foot = 75 lb. superload
15 lb. floor
60 lb. self-weight (say)

150 lb. total

$$M = 150 \times 17^2 \times \frac{12}{12} = 43{,}400 \text{ lb.-in. per ft.}$$

Using 10 in. × 10 in. × 6 in. high tiles with $1\frac{1}{2}$ in. concrete above and 3 in. ribs, we have an overall depth of $7\frac{1}{2}$ in., an effective depth of, say, $6\frac{1}{2}$ in., and a flange of $1\frac{1}{2}$ in. plus $\frac{1}{2}$ in. (for tile) = 2 in. The spacing of the T-beams is 10 in. + 3 in. = 13 in. centre to centre.

[1] See the author's *Reinforced Concrete Design*, Chapter XXIV.

Depth of neutral axis

$= 0{\cdot}384 \times 6{\cdot}5\text{in.} = 2{\cdot}50$ in.

Average stress on 2 in. flange

$= \frac{1{\cdot}50}{2{\cdot}50} \times 750 = 450$ lb. per sq. in.

Value of 2 in. flange 13 in. wide

$= 2 \times 13 \times 450 = 11{,}700$ lb.

Lever arm $= 5\frac{1}{2}$ in. (about)

Bending moment per rib

$= \frac{13}{12} \times 43{,}400 = 47{,}200$ lb.-in.

Total compression

$= \frac{47{,}200}{5\frac{1}{2}\text{ in.}} = 8{,}600$ lb. per rib

Against an allowable compression of 11,700 lb.

Although this floor has more strength than required, we should not use less than a 6-in. tile for such a long span.

$A_s = \frac{8600}{18{,}000} = 0{\cdot}477$ sq. in. per rib

One bar $\frac{7}{8}$ in. $= 0{\cdot}601$ sq. in.

Shear $= 150 \times \frac{17}{2} \times \frac{13}{12}$ in.

$= 1{,}380$ lb. per rib

$b'jd = 3 \text{ in.} \times 5{\cdot}5 \text{ in.} = 16{\cdot}5$ sq. in.

$\therefore$ Average shear stress $= 84$ lb. per sq. in.

Adopting the top detail in Fig 48 this stress is allowable, as the bent-up bars will assist the concrete.

The weight per square foot must be checked.

Weight per foot-run of rib

$= 13 \text{ in.} \times 1\frac{1}{2} \text{ in.} \times 12$ in. concrete

plus 6 in. $\times$ 3 in. $\times$ 12 in. ,,

plus $\frac{12}{10} \times$ one tile at 25 lb.

449 cub. in. of concrete = 39 lb

$\frac{12}{10}$ of one tile at 25 lb. = 30 lb.

69 lb. per 1 ft. of rib

— 13 in. wide

Actual weight per square foot $= \frac{12}{13} \times 69 = 63{\cdot}5$ lb.

We have slightly underestimated the self-weight, but we have a margin of safety in the compression flange and the area of steel provided.

Slab Cantilever Walls. For heights up to 13 ft. the type shown in Fig. 48A may be used. To find the general proportions use the expression—

$$\text{Base} = (\text{height}) \times \sqrt{\frac{3k}{4w}}$$

where k = lateral pressure on back of wall in pounds per sq. ft. of depth and w = weight of earth per cub. ft. In Fig. 48A if $k = 20$ lb. per sq. ft. per ft. of depth and $w = 100$ lb. per cub. ft.

$$\text{Base} = 10{\cdot}6 \text{ ft.} \times \sqrt{\frac{3 \times 20}{4 \times 100}} = 10{\cdot}6 \times 0{\cdot}387$$

$= 4{\cdot}1$ ft. say 4 ft. in practice.

Of this length of 4 ft. one third, or 1 ft. 4 in., should project in front of the wall to form the toe. These proportions bring the line of thrust on the middle third point with a maximum intensity of bearing pressure of $2w \times$ (height).

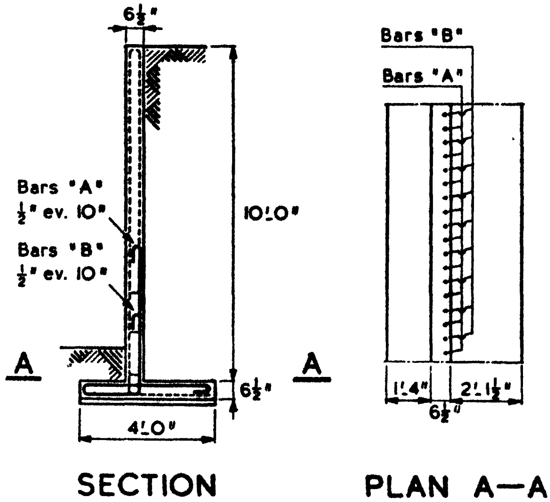


FIG. 48A. SLAB CANTILEVER WALL

In Fig. 48A $2w \times (\text{height}) = 2 \times 100 \times 10{\cdot}6$

$= 2{,}120$ lb. per sq. ft.

= say 1 ton per sq. ft. in practice

To calculate the reinforcement take sections 2 ft., 4 ft., 6 ft., 8 ft., and 10 ft. etc., below the top surface.

EXAMPLE. The slab cantilever wall in Fig. 48A is 10 ft. clear height and has to resist a pressure of 20 lb. per sq. ft. per ft. of depth. Design the section A–A at the base of the vertical portion.

SOLUTION.

$M = \frac{1}{6} \times 20 \times 10^3 \times 12 = 40{,}000$ lb.-in. per ft. run of wall

$$\text{Minimum } d = \sqrt{\frac{40{,}000}{126 \times 12}} = 5{\cdot}15 \text{ in.}$$

Use a $6\frac{1}{2}$ in. slab with $\frac{3}{4}$ in. cover giving $d = 5{\cdot}5$ in.

$$A_s = \frac{40{,}000}{18{,}000 \times {\cdot}872 \times 5{\cdot}5} = 0{\cdot}463 \text{ sq. in.}$$

Say $\frac{1}{2}$ in. bars at 5 in. centres $= 0{\cdot}47$ sq. in.

Chapter VI—COLUMNS

Rodded. The cross section of a column carrying a central load will be compressed equally over the whole area. The unit compressive *strain* in the steel is the same as the unit compressive strain in the concrete.

The unit compressive *stress* on the steel is therefore m times that on the concrete. The total safe load is therefore—

f_c (area of concrete) $+ mf_c$ (area of steel)
$= f_c$ (gross area) $+ (m - 1) f_c$ (area of steel)

With standard 1 : 2 : 4 concrete this is—

(600 (gross area) + 8,400 (area of steel) lb.)

As we have seen in Chapter III, columns of plain concrete are brittle and fail by shearing at 45°. To counteract the former, we should supply main bars having a sectional area of at least 1 per cent of the column section. To counteract the latter, we must supply *links* or *hoops* passing round the main bars.

These links also serve to bind the main bars in, and prevent them from buckling outwards. The sectional area of the main bars may be varied from 1 per cent to 5 per cent of the total area. In order to support the main bars and the concrete, the links or hoops should be spaced not farther apart than 16 diameters of the main bars, and not farther apart than half the diameter of the column. For columns having 1 per cent of main bars, the volume of the links should be about 0·2 per cent of the volume of the concrete; for 2 per cent of main bars, 0·4 per cent of links; for 4 per cent of main bars, say 0·6 per cent of links. Columns up to 18 in. by 18 in. may have only four main bars, but larger columns should at least have eight. Fig. 49 shows a variety of cross sections.

EXAMPLE. A column section is 20 in. × 20 in. It is reinforced with eight bars $1\frac{1}{4}$ in. diameter. What safe load will it take and what links should be supplied?

SOLUTION.

Area of main bars $= 7·95$ sq. in.

Percentage of section $= \dfrac{7·95}{20 \times 20} \times 100 =$ say, 2%

Safe load $= (600 \times 20 \times 20) + (8{,}400 \times 7·95)$
$= 307{,}000$ lb.

Using a pair of $\frac{3}{8}$ in. diameter links, the length of the outside link is about 70 in., and the length of the inside link is about 50 in., making 120 in. for each pair. The volume of one pair is $120 \times 0·11 = 13·2$ cub. in. Let the necessary spacing be x inches.

Volume of concrete

$= 20 \times 20 \times x$ cub. in.

Volume of link

$= 13·2$ cub. in. $=$ say, 0·4% of $20 \times 20 \times x$

$$\therefore x = \frac{13·2 \times 250}{20 \times 20} = 8·3, \text{ say } 9 \text{ in.}$$

The column is shown in the example in Fig. 50.

The treatment of columns under eccentric loading is difficult, and the reader is referred to more exhaustive treatises.

Hooped. Circular columns with very closely-spaced hoops or spirals, when tested to failure

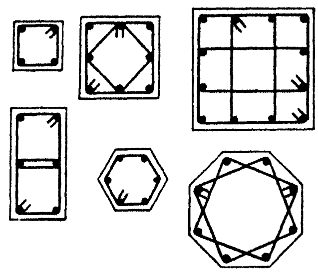


FIG. 49

in a testing machine, show higher strengths than rodded columns having the same total weight of steel reinforcement. However, before they attain this strength, they shorten by several inches. Such shortening is, of course, not permissible in an actual building, and it is not safe to rely on the full testing machine strength. Recent experiments also seem to show that hooped columns cannot support high loads indefinitely. When the load is left in position several days, failure will occur under much smaller loads. If the designer decides to use hooped columns, he will find regulations as to their strength in the new Code.

Arrangement of Steel Reinforcement. The lower ends of the main bars are placed just above the top of the floor or column footing, or just above some other main horizontal construction joint. In building work they need not have hooked ends. The top end is taken

about 30 diameters above the top of the next floor. In water towers, etc., where heavy bending stresses occur in the columns, a larger lap may be required. The tops of the bars, as a rule, require cranking to fall inside the upper column Some regulations call for a closer spacing of links at the ends of the column, but if no special regulations are enforced, then they may be spaced evenly. It is a little difficult to place the links marked X in the figure, but they should be put in if possible. An elevation of a typical column is shown in Fig. 50. Any one of the column sections in Fig. 49 may be

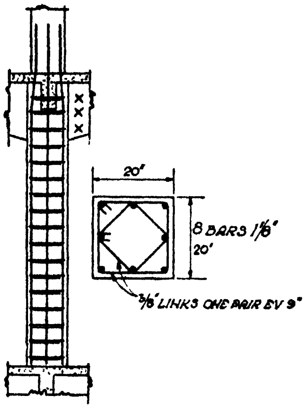


FIG. 50

arranged in a similar manner. If the external columns are allowed to show on the outside face of the building, then they should be made of the same width all the way up, by adopting sections similar to the left-hand bottom detail in Fig. 49 for the upper floors.

Footings. On good ground, column footings are best made square in plan. Small footings may be made of uniform thickness. Larger footings may be tapered towards the edges if the slope of the top is less than 1 in 5. A steep slope requires centering, which is very expensive. In such a case the footing may be stepped, as in the left-hand detail in Fig. 51. The right-hand column footing in Fig. 51 is designed to resist a cantilever moment of $\frac{pL_1^2}{2}$ lb. ft. per foot of cross-section, where p is the pressure per square foot on the ground. The footing slab must be thick enough to prevent the column from "punching" through it. The left-hand footing in Fig. 51 is designed for a moment of $\frac{pL_2^2}{2}$ at section y–y and for *beam* shear at this section. At section z–z a moment of $\frac{pL_3^2}{2}$ must be allowed for, and the punching shear round the column perimeter must be checked. A typical footing for a 6-in. wall (not a retaining wall) is also indicated in Fig. 51.

It is policy to make column footings of massive construction. In cases of heavy loading it is sometimes possible to bring the whole area of footing inside the 60° "spread" line (see

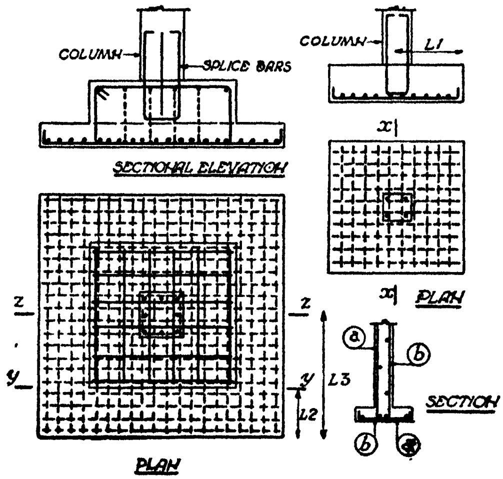


FIG. 51

Chapter III) by adding a little more concrete. It may then be treated as a plain-concrete footing with merely a nominal amount of steel. Pile caps for groups of two, three, or four piles may be 18 in. to 24 in. thick. Caps for five, six, seven, eight, or nine piles 30 in. to 36 in. thick.

EXAMPLE. A column 14 in. × 14 in. carries 70 tons. The ground will take 2 tons per sq. ft. Design a footing.

SOLUTION. Area required = 35 sq. ft., say 6 ft. × 6 ft. = 36 sq. ft.

Load passing directly from column to ground is 2 tons per sq. ft. on an area of 14 in. × 14 in. = 2½ tons, say.

Total punching shear

$$= 70 \text{ tons} - 2\tfrac{1}{2} \text{ tons} = 67\tfrac{1}{2} \text{ tons}$$

Punching shear area

$$= 4 \times 14 \text{ in.} \times \text{thickness of footing.}$$

Necessary thickness at a punching shear of 150 lb. per sq. in.

$$= \frac{67{\cdot}5 \times 2240}{4 \times 14 \times 150} = 18 \text{ in. thick.}$$

Make the footing of uniform thickness, like the right-hand detail in Fig. 51, 6 ft. × 6 ft. × 1 ft. 6 in. thick.

Moment

$$= \frac{4480 \times 3^2}{2} \times 12 \text{ lb.-in. per ft.} = 242{,}000 \text{ lb.-in.}$$

$$\text{Minimum } d \text{ at } 126\,bd^2 = \sqrt{\frac{242{,}000}{126 \times 12}} = 12{\cdot}7 \text{ in. only}$$

$$A_s = \frac{242{,}000}{18{,}000 \times {\cdot}87 \times 16 \text{ in.}} = 0{\cdot}96 \text{ sq. in.}$$

¾ in. bars every 5½in. = 0·96 sq. in. (both ways).

(Care should be taken to use fairly small bars to ensure sufficient grip-length.)

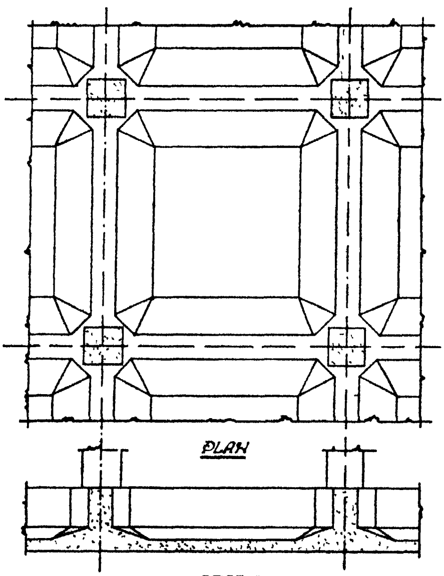


FIG. 52

Raft Foundations. When the individual column footings required are very large, they may be combined into a raft covering the whole site, particularly if the ground will not support piles at a reasonable depth. Where a raft is necessary, every effort should be made to space the columns in the superstructure at regular intervals, say every 20 ft. both ways.

If it is ***absolutely certain*** that the whole raft will be uniformly loaded and no settlement will result, a flat-slab design may be used. For all other cases a square-panel raft with deep beams both ways is the soundest design. True raft foundations are not often met with in this country, and their design under unequal loading is not easy. The reader is referred to more exhaustive treatises. A plan of a typical panel of raft, say 20 ft. by 20 ft., to carry a load of one ton per square foot, is shown in Fig. 52.

Fairly often it is convenient to cover the whole site with a reinforced concrete slab having a light mesh of bars. This is not a raft in the structural sense of the word, and the thickness is arbitrary. For an ordinary dwelling-house, or the ground floor of a workshop, 4 in. to 6 in. slabs with ½ in. or ⅜ in. bars, spaced 12 in. centres both ways, are common sections.

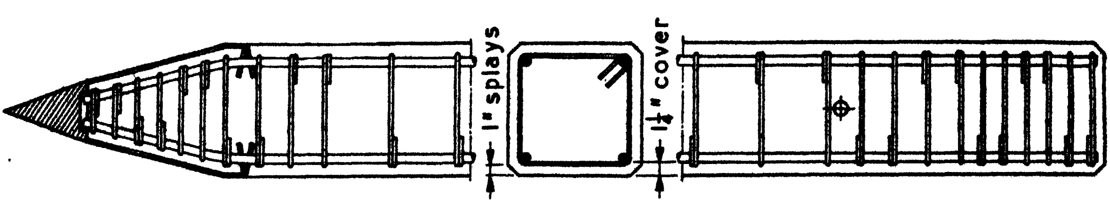
Reinforced Concrete Piles. Bearing piles as Fig. 52A, precast and driven when mature, are usual practice. Typical sizes and loads are—

10 in. × 10 in. up to 25 ft. long to carry 30 tons each.
12 in. × 12 in up to 35 ft long to carry 45 tons each.
14 in. × 14 in. up to 40 ft. long to carry 60 tons each.

Care must be taken in handling such piles and they should be driven by a hammer of at least half the weight of the pile to the following set (set in inches for ten blows)—

$$= \frac{20 \times (\text{weight of hammer in tons}) \times (\text{drop in feet})}{\left(1 + \dfrac{\text{weight of pile}}{\text{weight of hammer}}\right) \times \text{safe load in tons}}$$

Drops of 3 ft. to 4 ft. are usual.



¼" dia links spaced 2" and 3" in toe and head and 6" in body of pile

Main bars in 10" x 10" pile	⅝" up to 25'0"	¾" for 25'0" to 30'0"
do. do 12" x 12" pile	¾" up to 30'0"	⅞" for 30'0" to 35'0"
do do. 14" x 14" pile	⅞" up to 33'0"	1" for 33'0" to 40'0"

Concrete 1 : 1½ : 3

FIG. 52A

Chapter VII—REINFORCED-CONCRETE BUILDINGS

Materials. In large building work, the main alternative to reinforced concrete is steel-framed construction. The ruling factor is cost, and present-day practice is dependent on present relative costs. For one-storey commercial buildings, steel trusses and stanchions with brick walls are usual. Concrete will only be used in the foundations, floor, lintels, etc. For city buildings, steel-framed construction is almost universal.

The chief drawback to concrete for city buildings is its bulkiness, resulting in large, unsightly columns and beams. Its use is also limited by its weakness in shear. The lower floors of city buildings have often to carry very heavy loads on very shallow beams. Columns, lintels, etc., have to be hidden away in thin walls. Nothing but steel construction will fulfil all these conditions. In city buildings, therefore, concrete will only appear in the footings, floors, and fire-proof casing to the steelwork.

In factory and warehouse buildings, where appearance is not vital and regularity of construction is usual, reinforced concrete is very widely used.

Type. Having decided to employ reinforced concrete, we have a choice between flat-slab floors, square-panel floors, or slab-and-girder floors.

Flat-slab work, except for light loads, is the cheapest and quickest to build. The depth of floor construction in flat-slab work is about 12 in. less than in slab-and-girder work for an average floor. If each story has to have a specified clear floor height, then a flat-slab building would save 1 ft. in height for each story. However, flat-slab construction is only suitable for large rectangular sites with the columns spaced evenly both ways.

There should be at least four spans across the least dimension in plan, and the floor should be free from holes for chutes, lifts, trap-doors, etc. Square-panel floors also require a large number of square panels of equal size, free from holes, for successful application of this form of construction. (If it is possible to use square-panel floors, then it is usually possible to use flat-slab floors. The former, therefore, are seldom used.) For small or irregular sites, or where the floors are cut up with a large number of openings, then slab-and-girder floors must be adopted.

Spacing of Columns. Having settled on a type of construction, we must then fix the spacing of the columns. If the building is to be supported on a raft (which is not often the case in this country), this should be taken into account when deciding on a column spacing (see Chapter VI). The closer the spacing of the columns, the cheaper the building. However, a close spacing interferes with the proper use of the structure. Spacings of about 20 ft. by 20 ft. for flat-slab floors and 24 ft. by 16 ft. for slab-and-girder floors are average values for warehouse work. Flat-slab buildings are usually easy to arrange, and contain a large amount of repetition work. Slab-and-girder buildings are more difficult.

Slab-and-Girder Floors—Spacings and Loading. The columns are located by dividing the total length and breadth of the floor into a number of equal spaces. For example, if the floor is 60 ft. by 100 ft., we may divide it into 16 panels, each 15 ft. by 25 ft. In some cases it pays to divide the *overall* width up evenly (see Fig. 53). This means that the outside spans, measured centre to centre of columns, are smaller than the inside spans. The maximum bending moment is thus reduced in the outside spans until it is nearly equal to the maximum moment in the middle spans—making for uniformity of section.

It is difficult to lay down any rules for spacing columns in buildings of very irregular shape, each case requiring special treatment on its merits.

For very light loads, columns may be spaced out to 20 ft. by 30 ft. For very heavy loads they may be 12 ft. by 16 ft. Having spaced the columns, we have to decide on the spacing of the secondary beams. One secondary is always placed at each column, and the span of the main beams is usually divided into two, three, four, or five equal divisions. For example, if the main beam spans 25 ft., then we may divide this into three spaces of 8 ft. 4 in. or four spaces of 6 ft. 3 in. The spacing of the

secondaries is, of course, the span of the floor slab. A closer spacing allows us to use a thinner slab, but, as the slab forms the compression flange of the beams, a thin slab may not be sufficient to supply the necessary compression. For light floors, a 4-in. slab should be tried; and for heavy floors, say 3 cwt. per square foot and upwards, a 6-in. slab or thicker.

If there is any doubt about the best arrangement, several different ones should be tried. The floor slab spans from secondary beam to secondary beam, and for normal beams the span should be taken from centre to centre. If very wide beams are used, the effective span may be taken as the clear span plus the effective depth of the slab. The floor is, of course, all cast in one piece, but for purposes of calculation it may be looked on as composed of a series of long separate planks, each 12-in. wide. The load per foot run on each 12-in. width is the superload per square foot on the floor plus the self-weight per square foot of the slab. The moments to be designed for are given in Chapter IV.

The secondary beams carry a uniform load per foot-run which is equal to the weight per square foot of the floor-slab and superload multiplied by the spacing of the secondaries. In addition to this there is the self-weight of the beam.

If the main beam carries only one or two secondaries, then these should be treated as point loads. If there are three or more secondaries in each span, then the total load on one floor panel may be taken as uniformly spaced along each main beam. It will be seen in all the above that it is necessary to know the dead weight of the floor before we can find the maximum bending moments and shear forces that it has to carry. It is, therefore, necessary, before calculating the size of each member, to estimate what its self-weight will be. A little practice will soon enable the designer to form a close estimate.

EXAMPLE. A slab-and-girder floor has to carry a superload of 250 lb. per square foot and a timber floor-finish weighing 14 lb. per square foot. The columns are spaced 24 ft. × 18 ft., the secondary beams being spaced at 8 ft. centres. Design one internal bay of floor complete, using stresses of 750 and 18,000 lb. per square inch. ($m = 15$.)

SOLUTION. (This floor is shown in Fig. 53. In practice, the designer would make sketches of the different members as he designs them.)

Floor Slab Span 8 ft.

Load = 250 lb. per sq. ft. (superload)
14 lb. per sq. ft (finish)
Estimated self-weight (say) = 54 lb. per sq. ft.

318 lb. per sq. ft.

$$M = \frac{wl^2}{12} = 318 \times 8^2 \times \frac{12}{12} = 20{,}400 \text{ lb.-in.}$$

$$\text{Minimum } d = \sqrt{\frac{20{,}400}{12 \times 126}} = 3{\cdot}68 \text{ in., use a } 4\tfrac{1}{2}\text{-in. slab}$$

Actual $d = 3{\cdot}75$ in

$$A_s = \frac{20{,}400}{18{,}000 \times {\cdot}872 \times 3{\cdot}75} = 0{\cdot}345 \textit{ sq. in.}$$

$\frac{1}{2}$-in. bars spaced every $6\frac{1}{2}$ in. give 0·363 *sq. in.*

Secondary Beam Span 18 ft.

Load per ft. = 8 × 318 = 2,540 lb. (slab and superload)
Estimated self-weight (say) = 128 lb. per ft.

2,668 lb. per ft.

$$M = \frac{wl^2}{12} = 2{,}668 \times 18^2 \times \frac{12}{12} = 870{,}000 \text{ lb.-in.}$$

$$\text{Approx. width } b' = \sqrt[3]{\frac{870{,}000}{1800}} = \sqrt[3]{483} = 7{\cdot}85 \text{ in.}$$

$$\text{Shear} = F = \frac{wl}{2} = 2{,}668 \times \frac{18}{2} = 24{,}000 \text{ lb.}$$

@ 225 lb. per sq. in., $b'jd$ must be at least 107 sq. in.

Try a section 8 in. × 16 in. net.

$d = 18$ in, jd = about 16 in.

$$\text{Total compression} = \text{total tension} = \frac{870{,}000}{16} = 54{,}200 \text{ lb.}$$

Depth of neutral axis = 0·384 × 18 in. = 6·9 in.

$$\text{Average stress in compression flange} = \frac{4{\cdot}65}{6{\cdot}9} \times 750 = 508 \text{ lb. per sq. in.}$$

Value of flange per 1-in. width of B = 4·5 × 508 = 2,280 lb.

$$\text{Minimum } B \text{ required} = \frac{54{,}200}{2{,}280} = 23{\cdot}8 \text{ in.}$$

This is amply covered.

$$A_s = \frac{54{,}200}{18{,}000} = 3{\cdot}03 \text{ sq. in.}$$

4 bars 1 in. = 3·14 sq. in.

Shear strength—

$$f = \frac{24{,}000}{8 \times 16} = 187 \text{ lb. per sq. in.}$$

We will take all the diagonal tension on the steel—
2 bars 1 in. bent at 30° = 1·57 × 18,000 × $\frac{1}{2}$ = 14,200 lb.

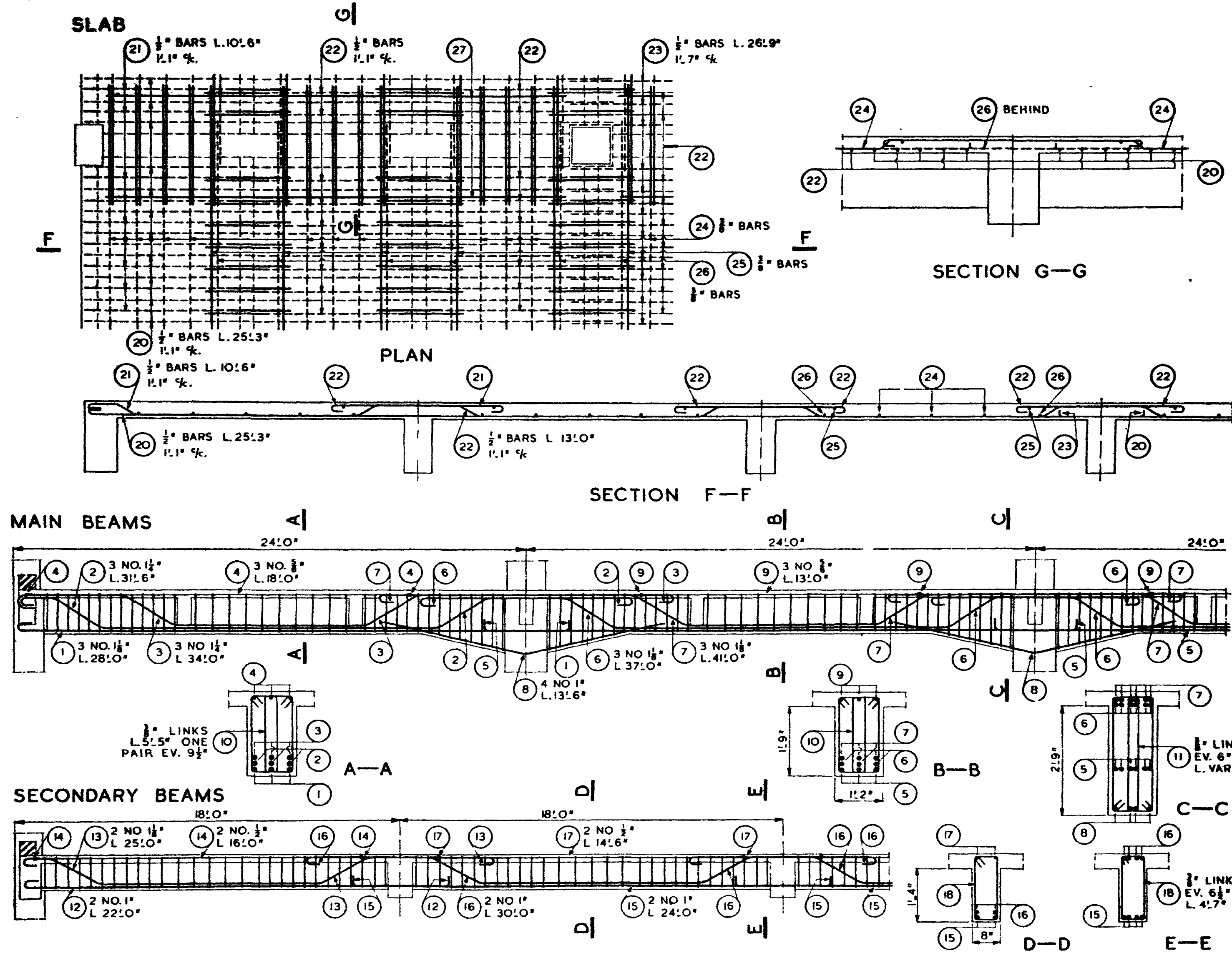


Fig. 53. Reinforcement Details of Floor

Stirrups must take 24,000 − 14,200 = 9,800 lb.

Area of steel in length jd (which is 16 in.) $= \frac{9{,}800}{18{,}000}$ = 0·545 sq. in.

Using $\frac{3}{8}$ in. stirrups having two legs, each stirrup will provide $2 \times 0{\cdot}11 = 0{\cdot}22$ sq. in.

The stirrups must be spaced $\frac{0{\cdot}22}{0{\cdot}545} \times \frac{16}{1} = 6{\cdot}48$ in, say $6\frac{1}{2}$ in.

These may be spaced out towards mid-span.

Main Beam Span 24 ft—Section near Mid-span.

Most of the load comes as point loads at the third points from the secondary beams. The self-weight of the beam is practically uniform and is a dead load.

Point loads = 2,668 × 18 ft. = 48,000 lb. each.

Self-weight of beam (say) about 300 lb. per foot.

Moment due to point loads = two-thirds of the "free" moment

$= \frac{2}{3} \times 48{,}000 \times 96$ in. = 3,070,000 lb.-in.

M due to self-weight

$$= 300 \times 24^2 \times \frac{12}{24} = \quad 86{,}000 \text{ lb.-in.}$$

$$3{,}156{,}000 \text{ lb.-in.}$$

$$\begin{aligned} \text{Shear} &= 48{,}000 \text{ lb.} \\ \text{plus } 300 \times 12 &= 3{,}600 \text{ lb} \\ \hline &\ 51{,}600 \text{ lb.} \end{aligned}$$

Minimum $b'jd$ area @ 225 lb. per sq. in. = 229 sq. in

Approximate $b' = \sqrt[3]{\frac{3{,}156{,}000}{1800}} = \sqrt[3]{1760} = 12$ in.

The size indicated is approximately 12 in. × 24 in. This would give a lever arm of about 23 in. and A_s about 7·7 sq. in. An arrangement of 9 equal bars would be nicest, and if we use 9 bars $1\frac{1}{8}$ in. we shall have 9·0 sq. in. This would allow us to reduce our lever arm to about 20 in.

Try a section 14 in. × 21 in. net.

d = 21·75 in. about, and jd = 19·75 in

Total compression = total tension $= \frac{3{,}156{,}000}{19{\cdot}75}$

= 160,000 lb.

$nd = 0{\cdot}384 \times 21{\cdot}75$ in. = 8·32 in.

Average stress on flange $= \frac{6{\cdot}07}{8{\cdot}32} \times 750$

= 545 lb. per sq. in.

Strength of $4\frac{1}{2}$-in. flange per 1 in. width

= 545 × 4·5 = 2,450 lb.

Width of B required $= \frac{160{,}000}{2{,}450} = 65{\cdot}2$ in.

We are allowed 14 in. + 12 × $4\frac{1}{2}$ in. = 68 in.

$$A_s = \frac{160{,}000}{18{,}000} = 8{\cdot}9 \text{ sq. in.}$$

9 bars $1\frac{1}{8}$ in. = nearly 9·0 sq. in.

Main Beam—Section at Support.

Try increasing the section 12 in., making $37\frac{1}{2}$ in. over all.

M from point loads (say) same as at mid-span = 3,070,000 lb.-in.

$$\text{Self-weight} = 300 \times 24^2 \times \frac{12}{12} = \quad 173{,}000 \text{ lb.-in.}$$

$$3{,}243{,}000 \text{ lb.-in.}$$

The section will function as a rectangular section with

b = 14 in. and d = about 34 in.

$bd = 14 \times 34 = 476$

$bd^2 = 14 \times 34^2 = 16{,}200$

$$R = \frac{M}{bd^2} = \frac{3{,}243{,}000}{16{,}200} = 200$$

Now A_s = 12 bars, $1\frac{1}{8}$ in. = 12 sq in,

i.e. $\frac{12}{476} = 2{\cdot}52\%$

From Fig. 26A we can satisfy this value of R if A'_s is about $\frac{1}{3} A_s$,

say use 4 bars 1 in.

The shear is practically constant for a distance of 8 ft. from the column centre line and is 51,600 lb From Fig. 53 it will be seen that we have two sets of bent-up bars following one another, each set consisting of 3 bars $1\frac{1}{8}$ in. bent up at about 60° (compare Fig. 34). As the shear is practically constant, we must take the whole shear on the smallest section of the beam.

$b'jd = 14 \times 19\frac{3}{4} = 276$ sq. in.

$$f = \frac{51{,}600}{276} = 186 \text{ lb. per sq. in.}$$

We will take all the diagonal tension on the steel.

Total shear	= 51,600 lb.
3 bars $1\frac{1}{8}$ in. @ 30° = 3 × 18,000 × $\frac{1}{2}$	= 27,000 lb.
To be taken by stirrups	24,600 lb.

Using double $\frac{3}{8}$ in. stirrups each pair has an area of 0·44 sq. in.

Area required in length $jd = \frac{24{,}600}{18{,}000} = 1{\cdot}37$ sq. in.

Spacing $= \frac{0{\cdot}44}{1{\cdot}37} \times 19\frac{3}{4} = 6{\cdot}3$ in.

Say one pair every 6 in.

The reader should draw out the moment of resistance for these beams as shown in Fig. 41 and compare this with Fig. 40.

Referring to Fig. 53 the reader will see that the distributors are bent up over the main beam as suggested by the new Code. Although at first sight this appears logical it is unnecessary.

Approximate Quantities in Floors. For making an estimate of cost without drawing out all the steel reinforcement, the quantities of concrete, steel, and centering may be run out as follows: First, the total area of floor slabs (square yards) and total yard-run of beam and column of each size are taken off. These are usually measured gross lengths, no deductions being made for intersections. Next, the quantity of concrete, steel, and centering required

for each square yard of floor slab and each yard-run of beam and column is estimated, and the whole is multiplied out and added up. These unit quantities may be estimated as under—

FLOOR SLABS. To find the cubic yards of concrete per square yard of slab, divide the thickness in inches by 36. The weight of steel in pounds per square yard is the area A_s in the calculations multiplied by 48 (including distributors). The centering required (gross) is 1 sq. yd. per square yard.

WALL SLABS. Concrete and steel as for floor slabs, but centering 2 sq. yd. per square yard.

BEAMS. To find the cubic yards of concrete per yard-run, divide the area of the projecting rib expressed in square inches by 36^2. The weight of steel in pounds per yard-run is the area A_s in the calculations multiplied by 18, plus the area A'_s multiplied by 6. The centering in square yards per yard-run is the girth (both sides plus bottom) in inches divided by 36. Where main beams are splayed out, the extra concrete, steel, and centering required for the splay must be worked out separately.

COLUMNS. To find the cubic yards of concrete per yard-run, divide the area in square inches by 36^2. The steel in pounds per yard-run is 15 multiplied by the area of main bars. The centering per yard-run is the girth in inches divided by 36.

For slabs and beams, the areas of steel A_s and A'_s should be the areas required for internal spans. (End spans require larger areas, but the bars are shorter.)

For computing the weight of steel, the total yard run of beam or column must be taken without any deductions for intersections.

EXAMPLE. Give the unit quantities of concrete, steel, and centering required for the floor slab, secondary beam, and main beam in Fig 53.

SOLUTION.

Floor Slab per square yard.

$$\text{Concrete} = \frac{4\cdot5}{36} = 0\cdot125 \text{ cub. yd.}$$

$$\text{Steel} = 0\cdot363 \times 48 = 17\tfrac{1}{2} \text{ lb.}$$

$$\text{Centering} = 1\cdot0 \text{ sq. yd.}$$

Secondary Beam per yard run.

$$\text{Concrete} = \frac{8 \times 16}{36^2} = \cdot099 \text{ cu. yd.}$$

$$\text{Steel} = 18 \times 3\cdot14 + 6 \times 0\cdot4 = 59 \text{ lb.}$$

$$\text{Centering} = \frac{16 + 16 + 8}{36} \text{ gross} = 1\cdot11 \text{ sq. yd.}$$

$$\text{or } \frac{16 + 16}{36} \text{ nett} = 0\cdot89 \text{ sq. yd.}$$

Main Beam per yard run (excluding splays).

$$\text{Concrete} = \frac{14 \times 21}{36^2} = 0\cdot226 \text{ cub. yd.}$$

$$\text{Steel} = 18 \times 9\cdot0 + 6 \times 0\cdot9 = 168 \text{ lb.}$$

$$\text{Centering} = \frac{21 + 21 + 14}{36} \text{ gross} = 1\cdot56 \text{ sq. yd.}$$

Main Beam Splays each.

$$\text{Concrete} = \frac{12 \times 14 \times 48}{1728} \times \frac{1}{27}$$

$$= 0.17 \text{ cub. yd.}$$

$$\text{Steel} = 70 \text{ lb.}$$

$$\text{Centering} = \frac{1 \text{ ft} \times 4 \text{ ft.} \times 2}{2} \times \frac{1}{9} = 0\cdot44 \text{ sq. yd.}$$

Staircases. This item occurs in most buildings. Small stairs may be supported in the centre only, as in Fig. 54, or they may be supported at both sides, as in Fig. 55. If a thick wall is available, the stairs may be made to cantilever out of it, as in Fig. 56. In these cases, the steps span from side to side. If the flight is short, it may be supported at top and bottom *only*, as in Fig. 57. In this case, the thickness t acts as a floor slab. The most common support is as shown in Fig. 58. The staircase is enclosed and supported all round the outside edge by a wall, and also at each landing level by a beam. In this case, also, the thickness t must be sufficient to act as a floor slab, but the bending moment is reduced by the side supports to a value of $\frac{wL^2}{25}$. Most stairs have some kind of a finish on the treads, so that it is possible to increase t as shown by a small splay.

EXAMPLE A staircase as in Fig. 58 has the dimension L equal to 16 ft. The stairs must carry a superload of 120 lb. per square foot. What thickness t is required and what main steel should be provided ?

SOLUTION.

Superload	= 120 lb.	per sq ft
Average weight of projections	= 45	,,
Slab (say)	= 87	,,
Finish	= 10	,,
Total load per square foot	= 262 on plan	

$$M = \frac{wL^2}{25} = 262 \times 16^2 \times \frac{12}{25} = 32{,}200 \text{ lb.-in.}$$

$$\text{Minimum } d = \sqrt{\frac{32{,}200}{126 \times 12}} = 4\cdot62 \text{ in., say a } 5\tfrac{1}{2}\text{-in. slab}$$

$$A_s = \frac{32{,}200}{18{,}000 \times 0\cdot872 \times 4\cdot75 \text{ in.}}$$

$$= 0\cdot432 \text{ sq. in., say } \tfrac{1}{2}\text{-in. bars @ 5 in. crs.}$$

That is, bar d is $\frac{1}{2}$ in. every 10 in. centres
bar e is $\frac{1}{2}$ in. every 10 in. centres
bar f is $\frac{1}{2}$ in. every 10 in. centres

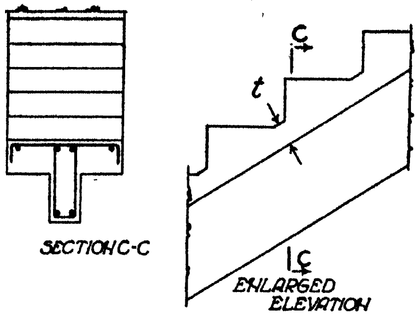


FIG. 54

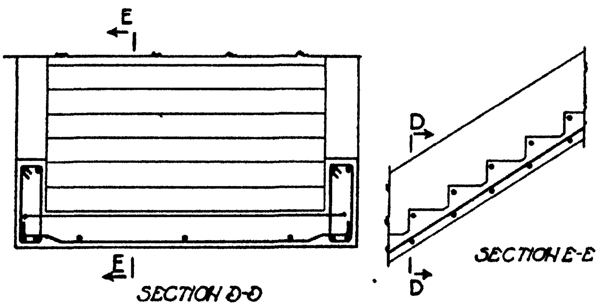


FIG. 55

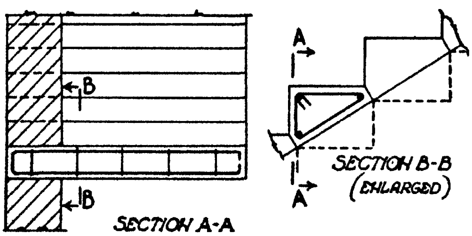


FIG. 56

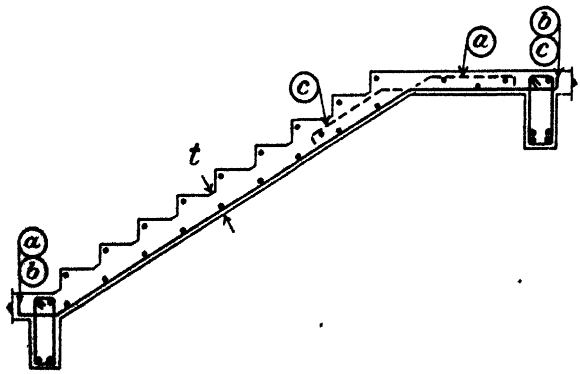


FIG. 57

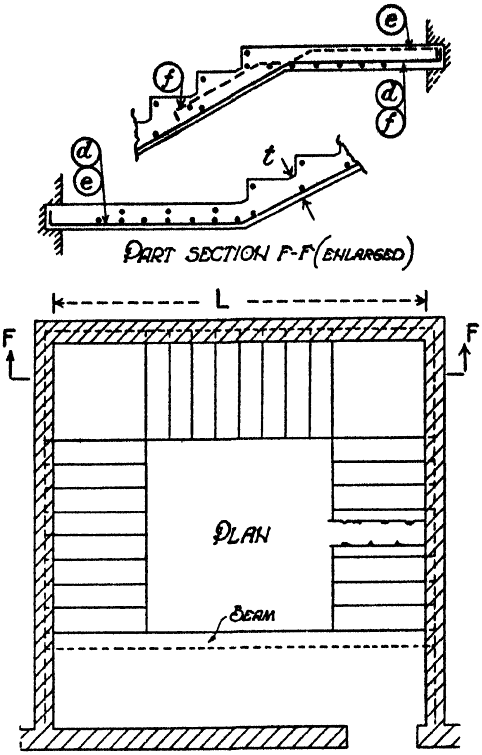


FIG. 58

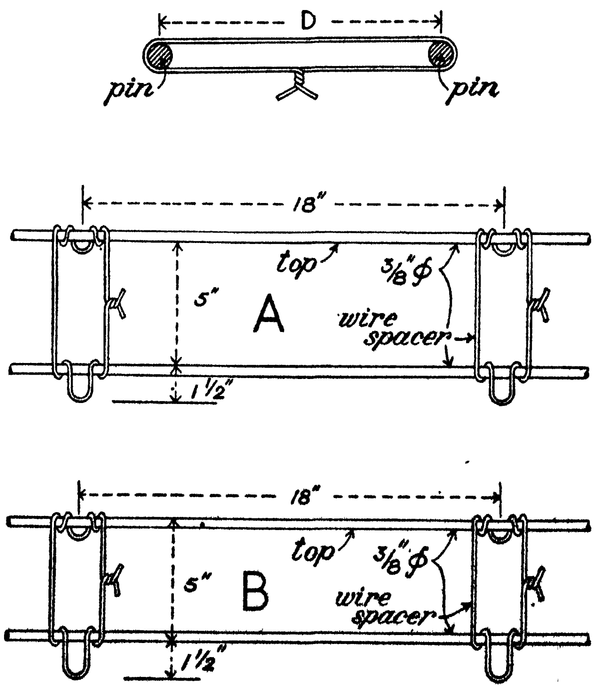


FIG. 59. ASSEMBLAGE OF DOUBLE-LAYER ROAD REINFORCEMENT

Roads. Reinforced concrete roads, where laid on porous material, should have, first, a skim of poor concrete (see Chapter III). For light roads, a total thickness of 6 in. and for heavy roads 8 in. may be worked to. Of this, the bottom part may be of 1 : 2 : 4 ballast concrete, the top 2 in. being 1 : 1½ : 3 mix with granite aggregate to form a wearing surface. Steel reinforcement is principally required for temperature changes. When the sun shines on the road, it expands and creeps over the foundation. When the temperature falls, it contracts and attempts to creep back over the foundation. Now, concrete has a small and unreliable tensile strength, and if the friction between the reinforced-concrete slab and the foundation is more than the tensile strength of the slab, then it cannot creep back, but stays where it is, leaving temperature cracks between each portion. The coefficient of friction between the two has a minimum value of 1·0. Suppose we have a slab 100 ft. long, and suppose the centre point remains in one position. As the temperature falls, the tensile strength at the centre should be sufficient to drag each half (50 ft. long) back over the foundation. If the slab were 8 in. thick and the coefficient of friction were 1·0, each 1-ft. width of section would support a tension of $50 \times 100 \times 1{\cdot}0$ lb. $= 5{,}000$ lb. If we rely on steel at 20,000 lb. per square inch, we shall require 0·25 sq. in. in one direction, say, ⅜ in. bars, every 10-in. top and bottom. With this reinforcement, the road could be laid with expansion joints (filled with bitumen) every 100 ft. Steel should be provided both ways (top and bottom) if the concrete is to provide the actual wearing surface, but this introduces the difficulty of supporting the top steel.

An excellent "home-made" reinforcement can be constructed as in Fig. 59. Alternatively, ⅜ in. links similar to the links in a beam may be supplied at the rate of one per square yard or thereabouts. The concrete should comply very strictly with the requirements given in Chapters I and II.

Panel Walls. If employed, these are usually lined inside with ceiling board to help insulation. They may be 5 in. thick reinforced with ⅜ in. rods at 12 in. centres both ways placed in the centre of the slab. It is more usual to use brick panel walls carried on bressummers.

Lintols in Brick Walls. Detached lintols are rectangular beams and may be designed for a value of $R = 126$.

EXAMPLE. An opening in a 14-in. brick wall is 10 ft. clear. The load on the lintol may be taken as a 60° triangle of 14-in. brick whose base is 10 ft. wide. Find a section.

SOLUTION.

$$W = \tfrac{1}{2} \times 10{\cdot}0 \times 8{\cdot}68 \times 140 \text{ lb.}$$
$$= 6{,}050 \text{ lb.}$$
$$M = \frac{WL}{6} = 6{,}050 \times 10 \times \frac{12}{6}$$
$$= 121{,}000 \text{ lb.-in.}$$
$$\text{Minimum } d = \sqrt{\frac{121{,}000}{126 \times 14}} = 8{\cdot}3 \text{ in.}$$

To suit the brick courses make 12 in. deep overall with d, say, 10 in.

$$A_s = \frac{121{,}000}{18{,}000 \times 0{\cdot}872 \times 10} = \begin{matrix}0{\cdot}77 \text{ sq. in., say,}\\ 4 \text{ bars } \tfrac{1}{2} \text{ in.}\end{matrix}$$

Reinforced Concrete Basements. The walls and floor of many basements, especially on wet sites, are built of reinforced concrete. It is possible to make a small basement watertight without using asphalt if the walls and floors are 1 : 1½ : 3 concrete, if the work is carried on continuously so that there are no old construction joints, and if great care is taken to keep construction joints clean and to work the new concrete thoroughly against the old. As an extra precaution, a strip of 20 gauge steel sheet 6 in. wide may be set 3 in. into the old concrete thus lapping 3 in. into the new lift at each joint. With large basements it is difficult to avoid old construction joints, and shrinkage stresses increase with linear dimensions. In most large basements therefore, a layer of asphalt (or bituminous sheets) is laid on 3 in. of mass concrete under the main basement floor and carried up outside the walls thus enclosing the basement in a "tank" of asphalt.

Chapter VIII—CONSTRUCTION

THE different methods of gauging, mixing, and placing have been discussed in some detail in Chapter II. A drawing must be made of the site, and the various stock-piles, mixers, towers, etc., disposed to give the easiest possible handling of materials without interfering with the space occupied by the actual structure. On a crowded site this is difficult, and needs a lot of careful attention. Every case must be treated on its merits.

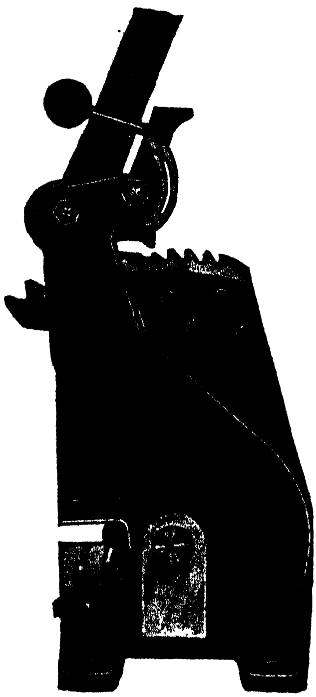


FIG. 60. LEVER BAR SHEARING MACHINE, FOR BARS UP TO $1\frac{9}{16}$ IN. DIAMETER

Made by Messrs C A. Hunton & Sons

Handling Reinforcement. It is the best plan to have the bars cut to length at the rolling mills. They should then be laid out on timber sleepers (preferably under cover) in their different diameters and lengths. If all bars are bought in long lengths and cut on site, 10 to 15 per cent waste may be expected. Bars up to 1 in. diameter may be cut in a single-lever shears as shown in Fig. 60. Larger bars may be cut in a geared shears, or, if in sufficient number, by an oxy-acetylene burner. The bar bender has a *descriptive list* of bars showing the length, shape, and distinguishing mark of each as indicated in Fig. 47. He requires a long bench to work on with a bar-bending machine at one end. Bars up to $1\frac{1}{8}$ in. diameter are best bent in a single-lever machine as in Fig. 61. Larger bars may be bent in a geared bender. Small links or stirrups $\frac{1}{4}$ in. or $\frac{3}{8}$ in. diameter are bent by means of a hand *link-bender* round short lengths of bar fixed in the top of the bench, or by a small edition of the machine shown in Fig. 61. Fig. 62 shows the operation of bending $\frac{1}{4}$ in. links for a 14 in. by 14 in. column. After bending, bars of each shape are bundled together and marked. The steel-fixer, working from the steel detail drawings, as Fig. 53, places the bars in position and wires them securely together with 16 or 18 gauge soft wire.

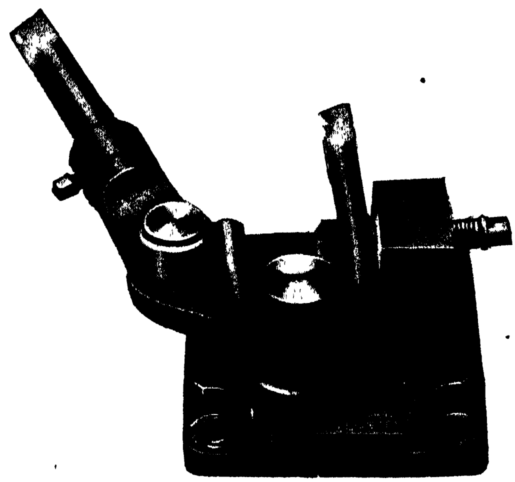


FIG. 61. SINGLE-LEVER BAR-BENDING MACHINE, FOR BARS UP TO 1 IN. DIAMETER

Made by Messrs C A. Hunton & Sons

An outstanding weakness of modern practice is the lack of care taken by some contractors to keep the bars in their proper place while the concrete is being rammed round them. An excellent way is to support the bars on small pre-cast blocks made of cement mortar.

Falsework. Between the time that the concrete is placed and the time that it can support its own weight, it must be contained by a timber casing, referred to as *shuttering*, *centering*, *forms*, or *moulds*. In the case of suspended floors, this

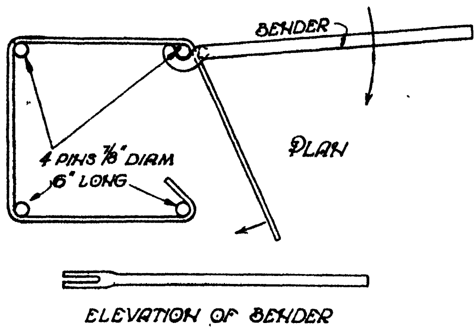


FIG 62. BENDING $\frac{3}{8}$ IN. LINKS FOR A 14 IN. BY 14 IN COLUMN

casing has to support the weight of the wet concrete. In addition to the vertical load, it is found that wet concrete, when rammed into the forms, acts as a liquid and exerts a lateral pressure equal to the vertical pressure. The problem of designing timber centering, therefore, is to design a temporary timber structure to contain liquid concrete weighing about 140 lb. per cub. ft. In addition to strength, this structure must possess sufficient rigidity to keep its original shape, or the finished concrete will be out of shape and out of line. Well-designed centering also must be easily erected, easily struck and cleared in correct rotation, and easily re-erected. The labour cost on timber centering averages three times the cost of the timber. To think out a good scheme for the centering for a complete building is not a task that can be lightly undertaken.

To begin with, the engineer who designs the building must continuously bear in mind that centering costs can often be considerably reduced by slight modifications of the sections of the beams and columns, or by a careful arrangement of the spans. Standardization must be aimed at, particularly for those pieces which are to be cleated together to form panels. For example, the side of a beam box usually forms a single unit, and it can generally be cleated together for use on the lowest floor, and struck and re-used for the upper floors with a few minor alterations.

Timber. The timber most commonly used in this country is good quality yellow deal. The face which is actually in contact with the concrete is planed, as are the edges of the boards that meet together. If a specially true surface is required, tongued and grooved boards may be used. If there is any chance of using both sides of the planking (this does not occur as frequently as might be imagined), both faces and both edges must be planed. The boards are, of course, bought ready planed.

The sizes quoted for timber are nominal, and do not allow for material cut away by the saw or planing machine. In addition to this, the outer surface of the joists and bearers gets damaged. In reckoning safe strengths at least $\frac{1}{8}$ in. should be allowed off all nominal scantlings. Thus $1\frac{1}{4}$ in. boards when planed are only $1\frac{1}{8}$ in. thick, and 3 in. by 9 in. joists only $2\frac{7}{8}$ in. by $8\frac{7}{8}$ in. Bearing in mind that the timber is used again and again and deteriorates with use, the following stresses and strains should not be exceeded—

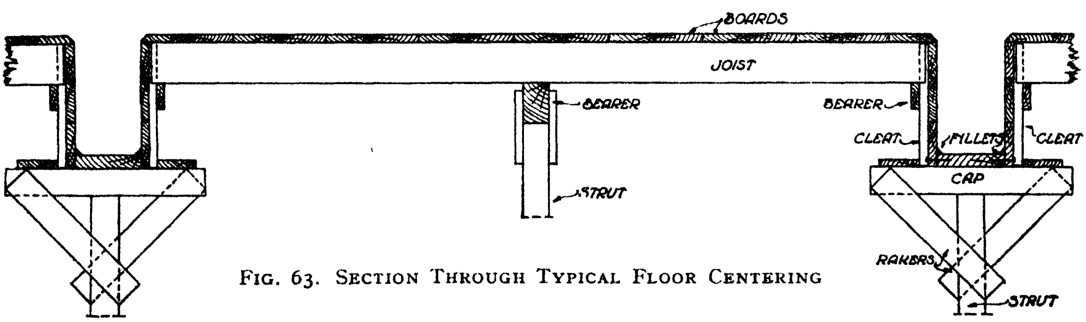


FIG. 63. SECTION THROUGH TYPICAL FLOOR CENTERING

TENSION AND COMPRESSION ALONG GRAIN	1,000 lb. per sq. in.
SHEAR	200 lb. per sq. in.
COMPRESSION AND BEARING ACROSS GRAIN	400 lb. per sq. in.
ELASTIC MODULUS	1,200,000 lb. per sq. in.

As rigidity of the centering is so important, we shall limit the maximum calculated deflection

of all members to $\frac{1}{10}$ in. and to one-six-hundredth of the span.

Sheathing or Planking. The facework consists of *boards*, usually 1 in, $1\frac{1}{4}$ in., or $1\frac{1}{2}$ in. nominal thickness. For suspended floors these are supported on *joists* spaced 2 ft. to 2 ft. 6 in. centres. For wall forms, the planks run horizontally and are supported by vertical members commonly referred to as *soldiers*, which again are generally supported by horizontal *walings*. Widths of board of 6 in., 7 in., and 8 in. are most useful.

The boards will, in general, run over several spans (see Fig. 63) and a moment of $\frac{wl^2}{12}$ may be taken on the span measured centre to centre of joists. The load per ft.-run of span for every 12 in. width of board is w, due to—

1. The weight of wet concrete at 140 lb. per foot of depth.
2. A small allowance for self weight of the boards which can generally be neglected.
3. An allowance for men working and wheeling concrete carts over the shuttering.

In order to cover item 3, the floor should be assumed at least 12 in. thick, that is, the weight of a full concrete cart is equivalent to a load of 140 lb. per sq. ft. on the boarding. Although the slab may be only 4 in. thick yet the boards should be designed as if it were 12 in. thick. This applies only to the design of floor *boards* and not to floor *joists*.

As the boards are continuous over several spans, there will be reversed moments over the joists. For a beam having a positive moment of $+\frac{wl^2}{12}$ at mid-span and a reversed moment of $-\frac{wl^2}{24}$ at each support, the deflection is $\frac{3}{384} \cdot \frac{wl^4}{EI}$. This deflection should not exceed about $\frac{1}{10}$ in. nor about one-six-hundredth of the span.

This point is very important and often limits the span. The shear stress on planking in normal cases is low and need not be calculated. To save the reader the trouble of carrying out the actual calculations he may use the graphs in Fig. 64.

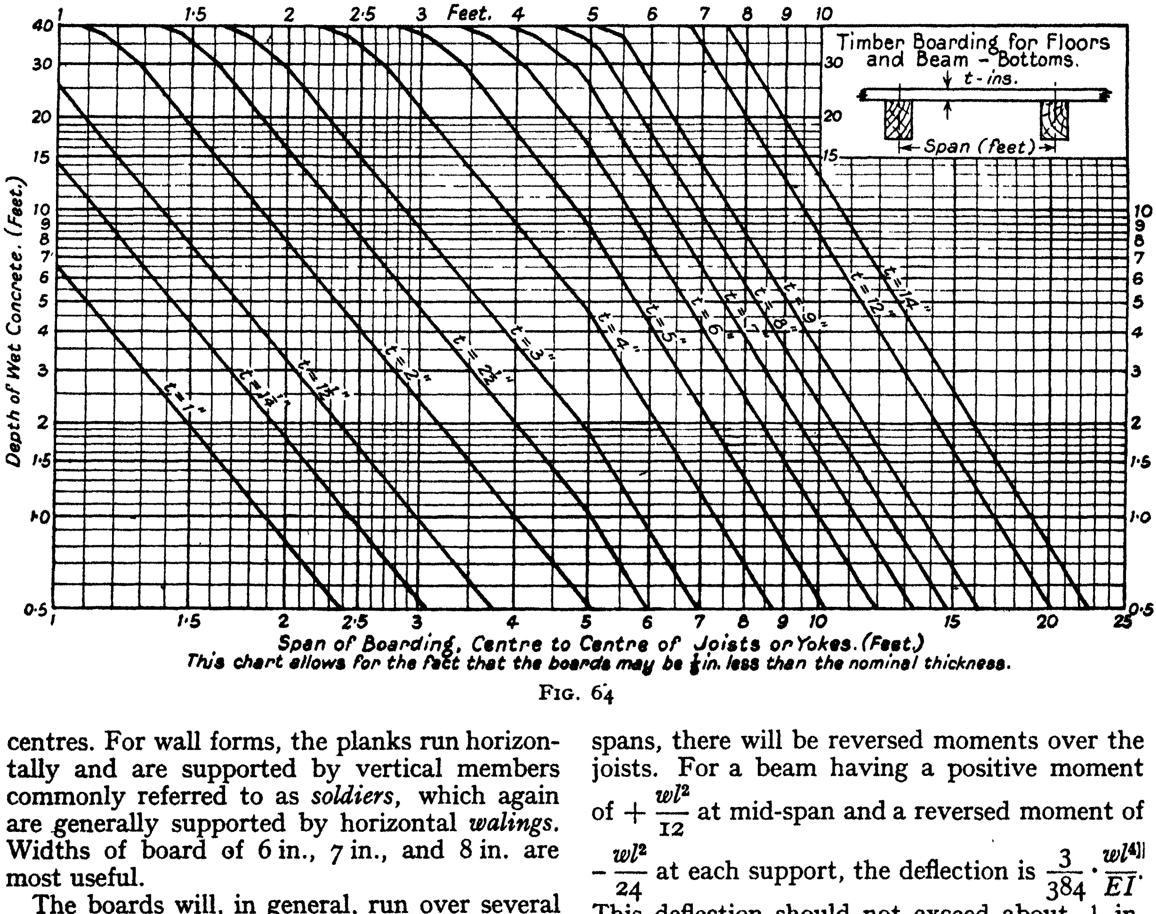


FIG. 64

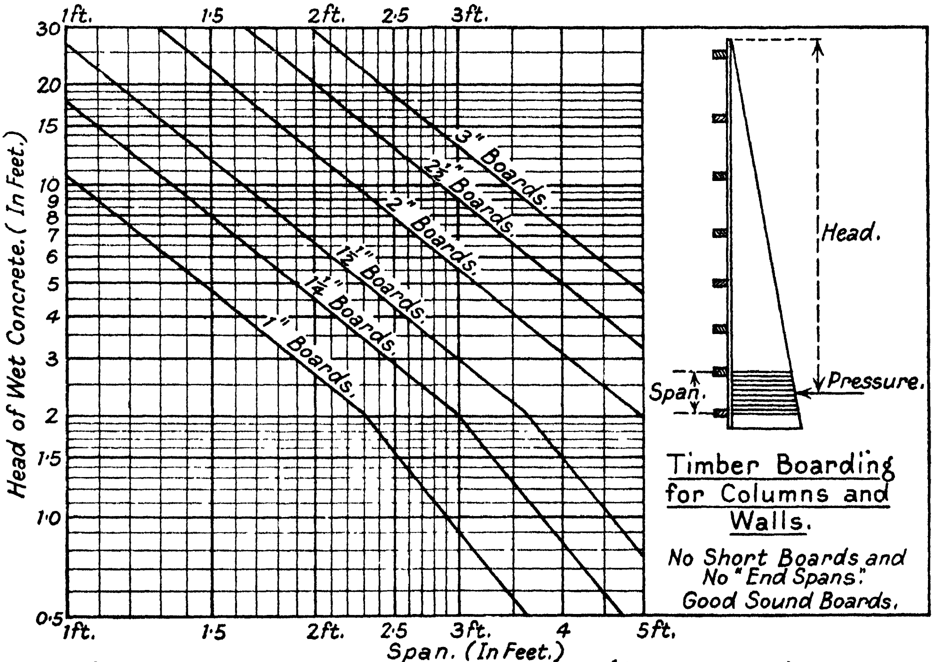
EXAMPLE. The boards to support a 6-in. reinforced concrete floor slab span 2 ft. 6 in. centre to centre of joists. What thickness is required?

SOLUTION. Although the floor is only 6 in. thick we must allow for 12 in. or the loaded concrete carts may break through the boarding.

From Fig. 64 a nominal thickness of $1\frac{1}{4}$ in. is very nearly strong enough theoretically and could just be used in practice.

Planking for wall forms is similar to planking for floors except that the boards are generally longer and more evenly loaded, and can therefore be allowed to span farther. Values for new boards in long lengths made up carefully into wall panels may be taken from Fig. 65.

If the joists have only one span, then the deflection will be $\frac{5}{384} \cdot \frac{wl^4}{EI}$ or $\frac{1}{6}$ in. instead of $\frac{1}{10}$ in. This should be remembered when reading the chart; and if a small deflection is required for a single span joist, then the next



This chart allows for the fact that the boards may be ⅛ in. less than nominal thickness.

FIG. 65

EXAMPLE. The boards for a wall form span 2 ft. 3 in. centre to centre of "soldiers." The maximum head of wet concrete is 5 ft. What boards are required?

SOLUTION. From Fig. 65. 1½ in. nominal boards will do.

Floor Joists. These usually consist of some section about 2½ in by 5 in. on edge spanning about 6 ft. and running across the short way of a floor panel. If the panel is less than say 8 ft. wide, the joists may carry right across, being supported at each end on the sides of the beam boxes. If the panels are 10 ft. or more wide, it is usually more convenient to supply a bearer half-way across as in Fig. 63. If in doubt, several different arrangements should be tried. In addition to their bending strength and stiffness, it is necessary to check the shear strength of the joists. All this may be done by using the alignment chart in Fig. 66. Note that the deflection has been calculated for a value of $\frac{3}{384} \cdot \frac{wl^4}{EI}$.

size larger than that shown by the chart must be used.

EXAMPLE. The planking for a 6-in. floor spans 2 ft. 6 in., centres of joists. The floor panel is 12 ft. wide with a bearer in the centre as in Fig. 63. What section joists are required?

SOLUTION. The load per ft.- run of joist is 6 in. of concrete multiplied by 2 ft. 6 in., or 0·5 ft. × 2·5 ft. = 1·25.

The span of the joists is 6 ft.

Draw a line across Fig. 66 from 6 ft. span on the left-hand vertical to 1·25 on the right-hand vertical.

For shear a 2 in. × 4 in. would do.

For bending strength either a 2½ in. × 5 in. or a 2 in. × 6 in.

For stiffness a 2½ in. × 5 in. is not quite enough and a 2 in. × 6 in. or a 3 in. × 6 in. would do or a 2½ in. × 6 in.

Most foremen do not like 2 in. × 6 in. as they are too high for their width and tend to tumble sideways while being placed. A 2½ in. × 6 in. is a very unusual section and difficult to procure. If the appearance of the underside of the floor were not important a 2½ in. × 5 in. would be used. If a good level surface were essential then a 3 in. × 6 in. would be used, or the

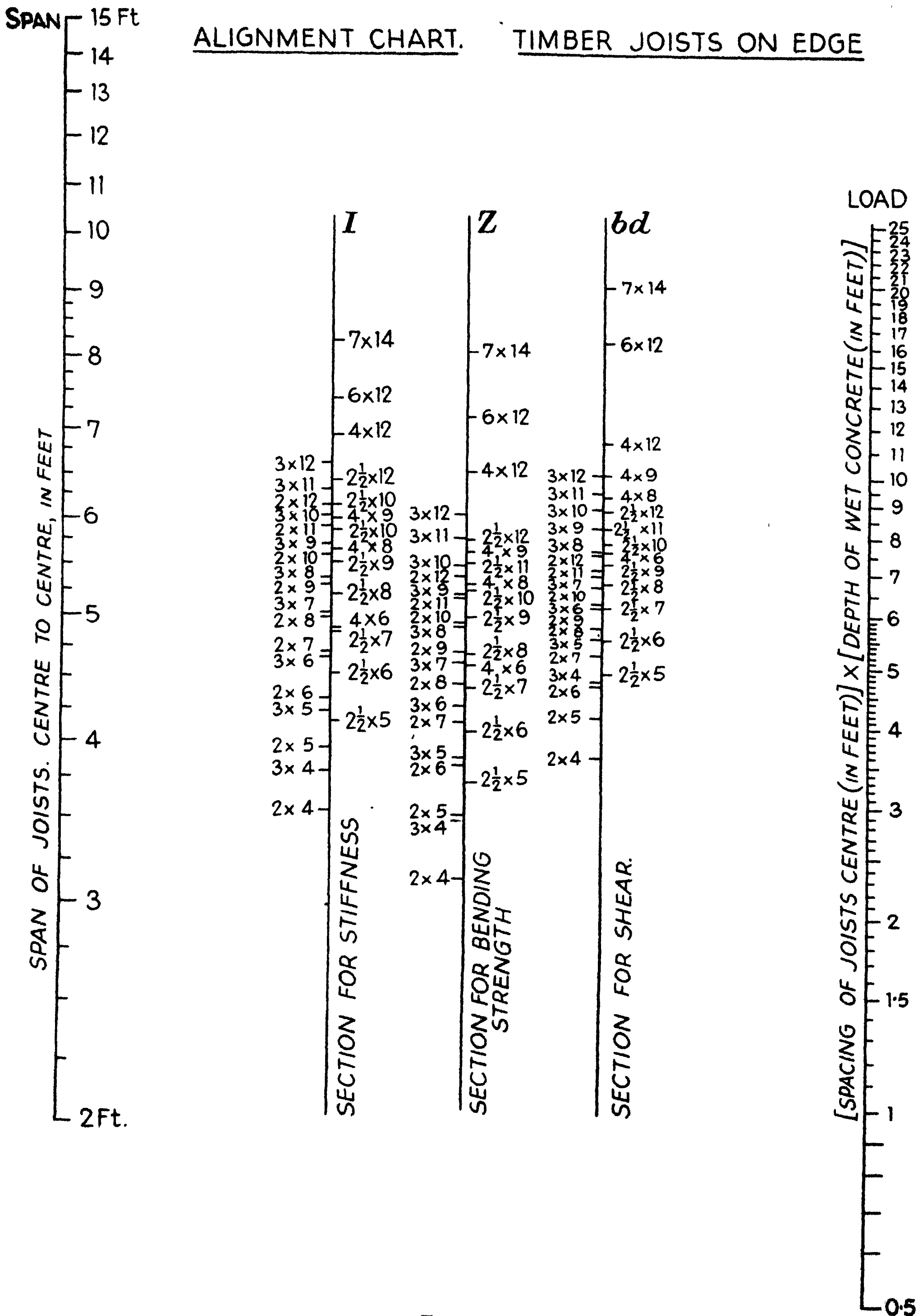

ALIGNMENT CHART.
TIMBER JOISTS ON EDGE
SPAN
15 Ft
2 Ft.
SPAN OF JOISTS. CENTRE TO CENTRE, IN FEET
I
SECTION FOR STIFFNESS
Z
SECTION FOR BENDING STRENGTH
bd
SECTION FOR SHEAR.
LOAD
[SPACING OF JOISTS CENTRE (IN FEET)] × [DEPTH OF WET CONCRETE (IN FEET)]
0·5

FIG. 66.

spacing of the joints centre to centre would be reduced to 2 ft. instead of 2 ft. 6 in. and a $2\frac{1}{2}$ in. × 5 in. joist used.

Bearers. These support the joists, and in addition to their bending strength, shear strength, and stiffness it is necessary to check the bearing stress or crushing stress across the grain. Although the load coming on the bearer from the joists consists of a series of point loads, we may in practice average these up and use Fig. 66 to find a solution, provided always that we remember to check the bearing pressure between the joists and the bearer and between the bearer and the struts.

EXAMPLE. The joists in the last example are supported by a central bearer. If this bearer is propped every 6 ft., what would be a suitable section for the bearer?

SOLUTION. Averaging out the load the bearer has to carry a 6 ft. width of 6 in. slab over a span of 6 ft. Treating it as a joist, the load is $6{\cdot}0 \times 0{\cdot}5 = 3{\cdot}0$.

Taking 3·0 for the right-hand vertical line in Fig. 66 and 6ft. span for the left-hand vertical line, and joining these points with a straight-edge, we find—

For shear a 2 in. × 6 in., a $2\frac{1}{2}$ in. × 5 in., or a 3 in. × 4 in. would do.

For bending strength a 2 in. × 9 in., a $2\frac{1}{2}$ in. × 8 in., a 3 in. × 7 in., or a 4 in. × 6 in. would do.

For stiffness a 2 in. × 8 in., a $2\frac{1}{2}$ in. × 8 in., a 3 in. × 7 in., or a 4 in. × 8 in. would do.

Coming to the practical side, it is best to use a bearer whose width is equal to that of the strut, which would be either 3 in. or 4 in. Therefore in practice either a 3 in. × 7 in. (if this section is available) or a 3 in. × 9 in. (which is always available) would be used with a 3 in. × 6 in. strut. Alternatively a 4 in. × 8 in. bearer with a 4 in. × 4 in. or 4 in. × 6 in. strut. A third arrangement would be to use two 3 in. × 6 in. sections side by side on a 3 in. × 6 in. strut turned sideways.

The reaction of each joist on top of the bearer is equal to the weight of an area 6 ft. by 2 ft. 6 in. of 6 in. floor or—

$$6 \times 2{\cdot}5 \times 0{\cdot}5 \times 140 \text{ lb.} = 1{,}050 \text{ lb.}$$

At 400 lb. per sq. in. this requires 2·62 sq. in. As the joists would be at least 2 in. wide and the bearer at least 3 in., their area of contact would be at least 6 sq. in.

The reaction between the top of the strut and the underside of the bearer is equal to the weight of an area of 6 ft. by 6 ft. of 6 in. floor or—

$$6 \times 6 \times 0{\cdot}5 \times 140 = 2{,}520 \text{ lb.}$$

At 400 lb. per sq. in. this requires 6·3 sq. in. As the bearer would be at least 3 in. wide and the strut at least 3 in. × 4 in., the area of contact would be at least 12 sq. in.

Struts, or Props. These are usually 3 in. × 4 in., 3 in. × 6 in., 3 in. × 9 in. or 4 in. × 4 in. section for average floor heights. The load that they will carry is limited by the bearing pressure between the head of the strut and the underside of the bearer or cap. (This could be avoided by using hardwood caps, but, taking everything into consideration, these are not desirable.) For a stress of 400 lb. per sq. in., a strut having a least thickness of 3 in. should be braced every 7 ft. 6 in. of height; for least thicknesses of 4 in. or 6 in. every 10 ft. or 15 ft. of height respectively. Such bracing need only be thin horizontal

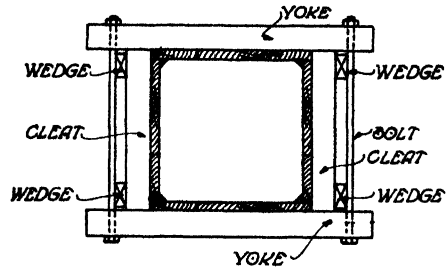


FIG. 67

boards with an occasional diagonal board. The struts under beam boxes, since they have to support both sides and bottom, are provided with a *cap* and small *rakers*.

Beam Boxes. These are made in three separate pieces, two sides and a bottom. The sides consist of boards (usually $1\frac{1}{4}$ in. or $1\frac{1}{2}$ in.) running horizontally with transverse cleats nailed across at

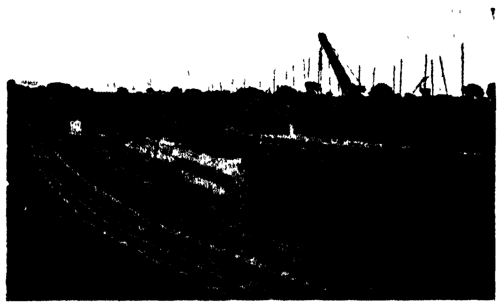


FIG 68. "BLAWFORMS" USED ON CORE-WALL, BARTLEY RESERVOIR DAM

(By permission of Messrs. Christmas & Walters)

intervals of 2 ft. to 2 ft. 6 in. As wet concrete behaves like a liquid, the sides have to resist horizontal pressure. The cleats span vertically, and for beams up to 2 ft. deep may be 6 in. boards on the flat. For deeper beams vertical cleats like small wall "soldiers" are required. The sides of very deep beams resemble the forms for a vertical wall. For isolated rectangular beams, the cleats are held together at the top by nailing strips of timber across the box.

For T-beams in floors, the tops of the cleats are supported off the boards or the floor joists. The bottom ends of the cleats may be held together by outside cramps, by passing wire ties on bolts through the beam, or most usually by special boards, or *ribands*, nailed to the caps of the struts. The beam bottoms are best made of 2 in. timber or thicker, and span from strut to strut. They are assisted by the fact that a few nails are always driven where shown in Fig. 63, and they may be allowed to span a little farther than indicated by Fig. 64.

EXAMPLE. A beam bottom has to carry 2 ft 6 in. of wet concrete and is made of 2 in. boards. How far may this span?

SOLUTION. From Fig. 64 a span of 3 ft. is safe. Taking everything into consideration a span of 3 ft. 3 in. might be used.

Boxes for the beams on the outside edge of floors have unequal sides. Their outside faces are usually supported by two rows of struts, a cantilever, and a knee-brace.

Column Boxes. The box is usually of four separate sides, consisting of vertical boards, say $1\frac{1}{4}$ in. thick, held together by cleats. The four sides are held together by *yokes*, or clamps. Steel clamps are now usually employed for all normal column work, but where timber yokes are employed they consist of two pieces of timber about 3 in. × 4 in. and two bolts $\frac{5}{8}$ in. or $\frac{3}{4}$ in. diameter. Tightening the bolts supports two of the sides, while the other two are held by wedges as shown in Fig. 67. The spacing of the yokes is governed by the depth of wet concrete. For example, if a column box is 12 ft. high and the whole of the column is poured at once, the lateral pressure will vary from 12 ft. at the bottom to nothing at the top. If the box were made of $1\frac{1}{4}$ in. boards the spacing of yokes at the bottom would be 14 in. (see Fig. 65). At a depth of 6 ft. the spacing could be 20 in., while at 3 ft. it could be 29 in. For large column boxes four yokes and four bolts are required, and the strength of yokes, bolts and washers must be checked. Bolts less than $\frac{5}{8}$ in. diameter are not used in practice.

Wall Forms. Most walls are shuttered on both sides, the shutters being tied across and supporting one another. Steel shutters are usually tied together with wire ties which are cut off after striking, and the ends turned and driven back into the green concrete. All-timber shutters are usually bolted across. Bolts are usually greased, turned during setting, and driven out after striking. The arrangement in Fig. 69, where the hook bolt remains in the concrete, is useful on high walls shuttered on one face only.

An excellent modern arrangement which obviates passing any ties through the concrete is the well-known Parry clamp illustrated in Fig. 70. The bolt is *above* the lift of concrete. For timber wall forms, the boards run horizontally and are supported by vertical studs, or *soldiers*. The tie-bolts may be passed through the studs, but it is more convenient to put horizontal walings outside the studs and pass the bolts through these. The strength of the boards is easily found from Fig. 65. The strength of the studs and walings should be checked, remembering that the load per square foot is not uniform. Small sections may be used, as the spans are easily reduced by adding intermediate ties.

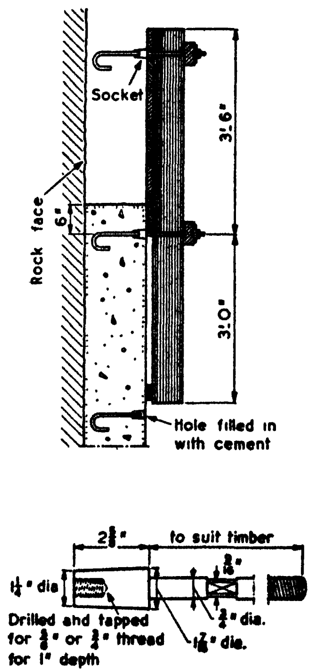


FIG 69. HIGH WALL SHUTTERED ON ONE FACE

Of late years the use of steel forms has been developed considerably. In all cases where a set of forms is to be used again and again, steel forms should be considered. There are firms who specialize in selling or hiring steel forms, and they should be consulted for all cases of repetition work.

When timber facework has been used six

to ten times, it is generally not in a state to give a reasonably decent surface, and must be scrapped. Steel forms, if carefully handled and stored, may be used indefinitely. An example of their use is given in Fig. 68.

ERECTING AND STRIKING FORMS. Panels weighing more than 2 cwt. are difficult to handle as one piece unless near the ground. This limits the use of panel construction to a great extent. For easy striking, all forms require to have clearances of a fraction of an inch. The reader should examine very carefully the details of all formwork which he sees. Forms should be thinly coated with mould-oil before use, but care must be taken to avoid dropping oil on the steel reinforcement. A rough average figure for the wastage of timber on an average job is half a cubic foot per square yard of surface. Some of this may be saved by using permanent adjustable shores (see Fig. 71), which may be re-used indefinitely, instead of timber struts, which are scrapped after one job.

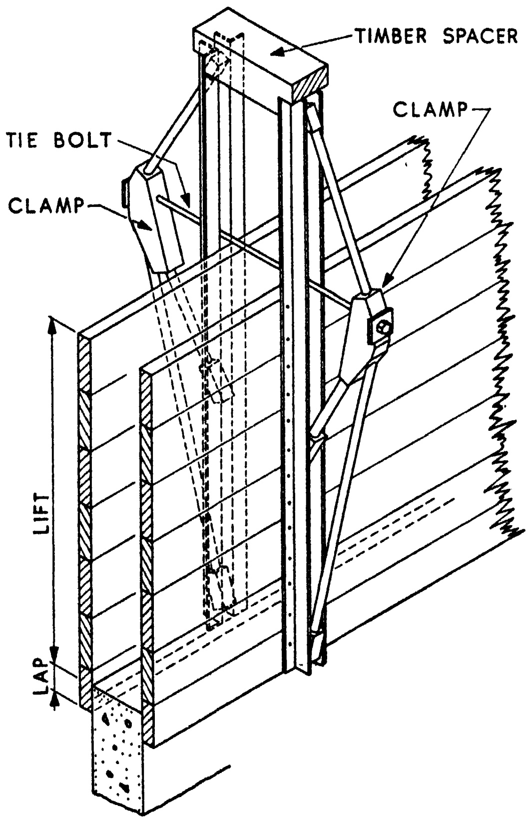


FIG. 70. THE PARRY CLAMP

Surfacing Concrete. The older idea of using a poor mixture of concrete and supplying a good surface by plastering it over with a sand-and-cement rendering is giving place to methods of using better concrete and better formwork, and then rubbing down or picking over the surface. For commercial building work, the surface is rubbed down with carborundum stones to remove the more prominent "boardmarks," at the same time applying a thin cement wash to fill up the small air pockets in the surface. For architectural effect, special coloured aggregate may be used. After the centering is removed, the surface is then treated to expose the aggregate by removing the cement. This may be done by using a power grinding machine to give a finished surface, or by brushing the green concrete with a wire brush, or by treating the surface with dilute acid. Floor finishes of the mosaic and terrazzo type are usually laid by specialists and are not undertaken by the general contractor. For a wearing surface a 1 in. layer of 1 : 1 : 2 cement, sand, and granite chippings may be laid before the floor itself has set. For non-slip stair treads, a cement rendering with carborundum sprinkled in the top surface may be applied. Road surfaces may be treated with a solution of sodium silicate.

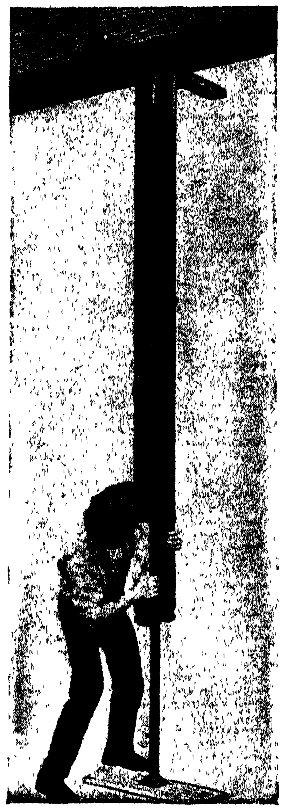


FIG. 71
METHOD OF PLACING A "ROOSHOR"
This shore can easily be placed, adjusted to any height, and struck without the use of any wedges, tools, etc.
(*Reproduced by permission of Messrs. Cowan Hulbert, Ltd.*)

Vibration. Turning to Fig. 13A in Chapter II we find, set out in a chain, the various processes in making concrete. To improve the chain we must strengthen the weakest link, which is number 10. Numbers 2 and 3 present

no technical difficulty as adequate crushing, washing, and screening plant can readily be designed, but there are still far too many pits with obsolete or inefficient plant. Number 10 remains the main difficulty in reinforced concrete. The designer can assist greatly by using rational sections and a sensible arrangement of bars. Most regulations and codes are very weak in this respect. To overcome the difficulty the use of electric or compressed air vibrators has been tried. For isolated pre-cast units, including large pre-cast piles, their use has had excellent results, but the writer, who has for years been urging some form of mechanical concrete placer, must confess that their use in cast-in-situ work has disappointed him, and we still await the machine that will do for number 10 what the power-driven mixer has done for number 7.

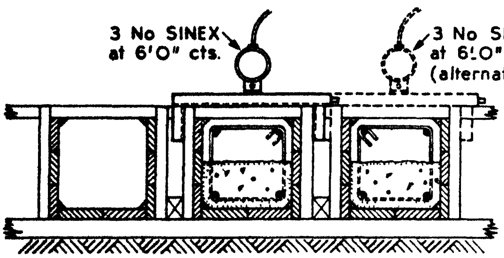


FIG. 72. PILE VIBRATING ARRANGEMENT

An arrangement used for vibrating 16 in. × 16 in. piles is shown in Fig. 72.

Pre-Stressing. Unless kept continually wet, modern concretes shrink after hardening. With normal Portland cement the shrinkage (apart from any temperature effect) at one month is about 0·01 per cent, at three months 0·02 per cent, at twelve months 0·03 per cent, and at two years is 0·04 per cent. Owing to the adhesion between the concrete and the steel, this shrinkage tends to put the steel into compression and the concrete into tension. If we construct a small vertical column such as a lamp standard, which carries little or no load, with heavy vertical reinforcement, the shrinkage of the small section of concrete is prevented by the heavy area of steel, and fine shrinkage cracks may open at intervals. These are of no importance as far as structural strength is concerned, but may lead to deterioration due to moisture entering the cracks. (In a *loaded* column, of course, the applied load prevents these cracks.)

To counteract the shrinkage effect, it is possible to pre-stress the steel by putting it under heavy tension and holding it in tension until the concrete has set and hardened. Fig. 73 shows diagrammatically how this may be done. The main rods are screwed at each end and held by removable end-pieces similar in principle to the sockets in Fig. 69. A complete steel frame is placed round the mould, and the tensioning nuts are screwed up until the calibrated springs shorten to their correct predetermined length. The mould is then filled with concrete and left until the concrete hardens. The end-pieces are unscrewed and the frame removed. In order to make sure of gripping the newly hardened concrete, deformed bars or bars with small end anchors welded or screwed on should be used. Large pre-cast units require heavy apparatus, and applications of pre-stressing to large cast-in-situ work would require heavy and elaborate apparatus with multiple strain gauges to ensure successful working. If the concrete actually shrinks 0·04 per cent, and the value of E_s is 30,000,000 lb. per sq. in., a stress of 12,000 lb. per sq. in. on the steel before casting would mean that both steel and concrete would be under zero stress when shrinkage was complete.

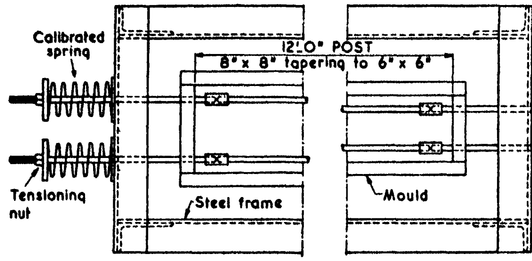


FIG 73 COUNTERACTING SHRINKAGE

Pre-stressing has been applied with some success to large circular tanks.

Chapter IX—PRE-CAST CONCRETE

BY W. C. EDWARDS

THE manufacture of pre-cast concrete products is a large and growing industry and, in addition to the well-established paving slabs, kerbs, fence posts, pipes, and telephone kiosks, such articles as lamp columns, road island bollards, cable covers, transmission poles, railway sleepers, and pre-fabricated buildings are becoming more popular. Fig. 74 and Fig. 75 show two interesting examples of modern pre-cast concrete. At present many pre-cast products are the outcome of the need for alternatives to timber and steel which are in short supply owing to the war, and it is doubtful whether some of these will retain their popularity when normal conditions return. Also the future development of the "cellulosic" and other "plastics" may ultimately offer serious competition to some branches of the pre-cast concrete industry.

FIG 74. PRE-CAST CONCRETE LAMP COLUMN

The great difference between pre-cast and cast-in-situ concrete is that the former is a factory-made product. Modern pre-cast works turn out, with a high-class finish, well-made products, varying from simple paving slabs to elaborate artificial stone.

Many large firms specialize in the manufacture of standardized products, and their works are laid out to mass produce these articles. Others undertake the manufacture of any pre-cast work to architects' specifications which may call for complicated purpose-made moulds.

The materials used for pre-cast work are similar to those employed for concrete work generally (see Chapters I and II). Crushed granite is in great demand as an aggregate, and a variety of other crushed stones and coloured cements are in use, depending on the finish required.

Many pre-cast products are made without steel reinforcement, but if the concrete is liable to be subjected to bending stresses either during handling or after it is put into use, then reinforcement will be necessary to carry the tensile stresses. The amount of reinforcement is calculated in accordance with the general principles used for the design of reinforced concrete (see Chapter IV).

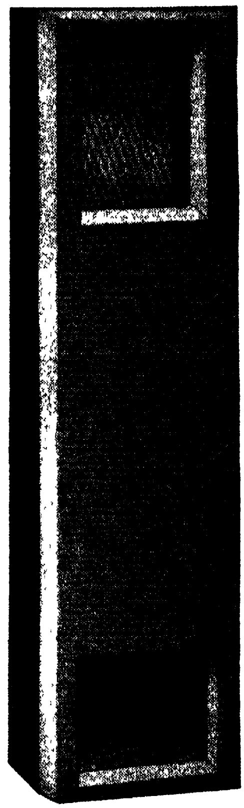


FIG. 75 CONVECTOR CASE FOR ELECTRIC HEATER

The problems in the manufacture of pre-cast products are many and varied, the most important being the following—

1. Lay-out of factory.
2. Mould making and maintenance.
3. Fabrication of reinforcement.
4. Concrete mixing and filling of moulds.
5. Finishing.
6. Handling, curing, and dispatch.
7. Works maintenance and stores.

Lay-out of Factory. This will depend largely on the type of product to be manufactured and how the bulk of delivery is to be made. Good road access to the loading bays is essential, and where highly specialized products are to be

manufactured for delivery all over the country, facilities for rail transport must be provided.

The production of paving slabs, pipes, and such repetition units is quite straightforward, and provision will be necessary for raw materials, concrete mixers, presses, or spinning machines, curing, stacking and loading for dispatch.

The manufacture of artificial stone is more complicated, and every process requires skilled workers and supervision.

A diagrammatic lay-out of an artificial stone plant is shown in Fig. 76. Fig. 77 shows poles being loaded into wagons for transport by rail.

Mould Making and Maintenance. Moulds for pre-cast work are made from timber, steel, plaster, gelatine, or sand, according to the amount of repetition called for and the shape of the product.

For repetition work it is essential to have either steel or very robust and well-made timber moulds, and care must be taken to see that they are kept in good repair if high-class work is to be produced.

For artificial stone the moulds are generally made of timber, with plaster, gelatine, and moulding sand for the more complicated articles. Great care must be exercised in making the moulds so that they will fill and strip easily. Fig. 78 shows a mould made from timber and steel for the manufacture of pre-cast concrete sleepers.

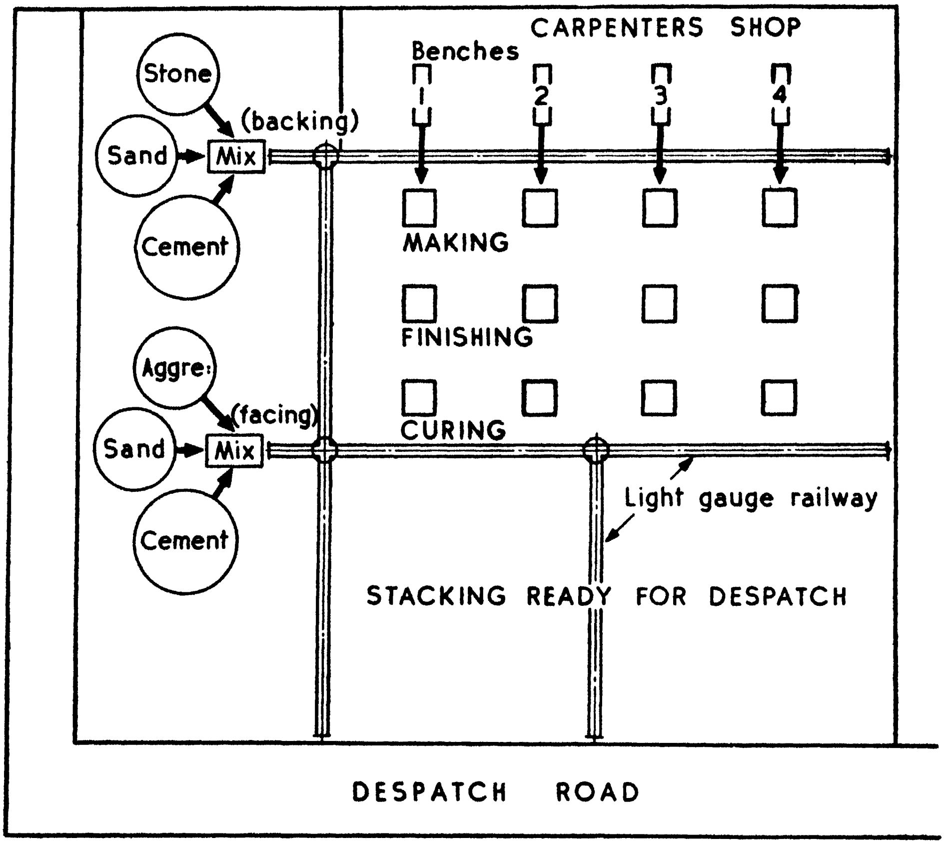


Fig. 76. Diagrammatic Arrangement of Artificial Stone Plant

Fabrication of Reinforcement. Where steel reinforcement is used, each bar must be accurately bent to a jig, and the reinforcement for each complete unit assembled into a rigid skeleton, preferably by spot welding together. The reinforcement must be designed with this in view and trained ironworkers employed.

Concrete Mixing and Filling of Moulds. Concrete mixing and placing is a most important

stage in the manufacture of pre-cast concrete, and must be carefully controlled if sound pro-

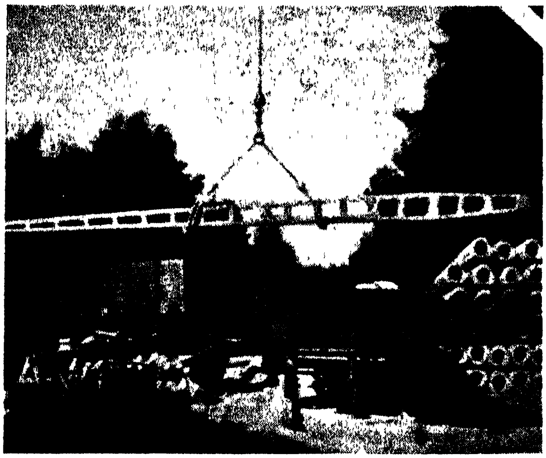


FIG. 77. LOADING PRE-CAST POLES INTO RAIL WAGONS

ducts are to be made. In many works where large outputs of a standard product are required, the concrete mixing is often directly controlled by the firms' laboratory staff in order that a uniform mix of the correct consistency is maintained.

Many different types of concrete mixers are used, varying from small mixers to large batching plants (Figs. 11 and 12), and depending on the type of product, size of factory, and speed of production.

The consistency of the mixtures used is governed chiefly by the methods for consolidating the concrete in the moulds. For hand or mechanical tamping and vibrating, the mixture will generally be just damp, as these methods of consolidation tend to make the concrete "sloppy." For hydraulic pressing the concrete is made very wet as this process squeezes out any surplus water.

For artificial stone, the moulds are generally filled by hand, and hand tamped or vibrated; paving slabs are usually made in hydraulic presses; posts, poles, sleepers, etc., are vibrated either by attaching electric vibrators to the moulds, or by placing the moulds on mechanically vibrated tables. The bulk of concrete pipes is now spun, a method of casting where use is made of centrifugal force. Fig. 79 shows a simple vibrating table, and Fig. 80 shows two pipes in the process of being spun. In the latter illustration it should be noted that only an outside steel mould is used, a small roller controlling the thickness of the pipe and forming a smooth face inside.

Finishing. Where a good finish is required, trained finishers should be employed to ensure a high-class article. The finishing should be done as soon as possible after stripping.

Artificial stone is usually finished in a similar manner to natural stone, and various methods are adopted to attain that end. Electrically-driven machines can be obtained for tooling or bush hammering. Where a smooth or polished surface is required, the product is rubbed either by hand or machine with carborundum blocks or discs. Fig. 81 shows an electrically-driven portable carborundum disc being used for surfacing cast stone.

Products such as posts, sleepers, etc., are usually left as they come from the moulds.

Spun pipes are, of course, finished during the process of manufacture, and Fig. 82 illustrates the good finish obtained on the internal surface of the pipe after spinning.

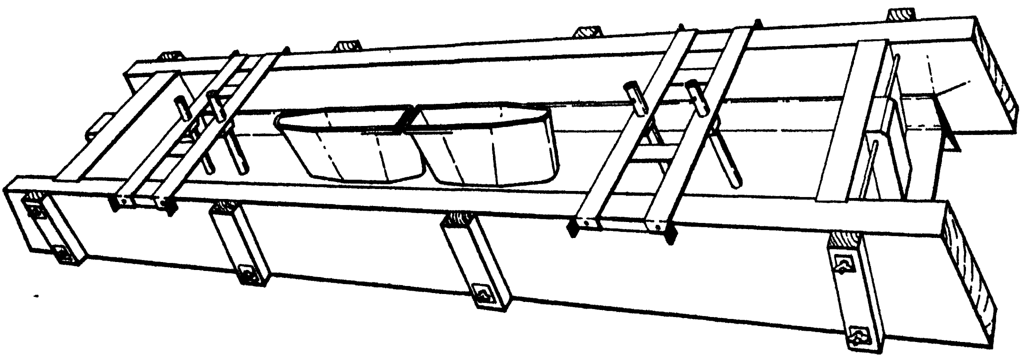


FIG. 78. TIMBER AND STEEL MOULD FOR MAKING PRE-CAST CONCRETE SLEEPERS

FIG. 79. VIBRATING TABLE

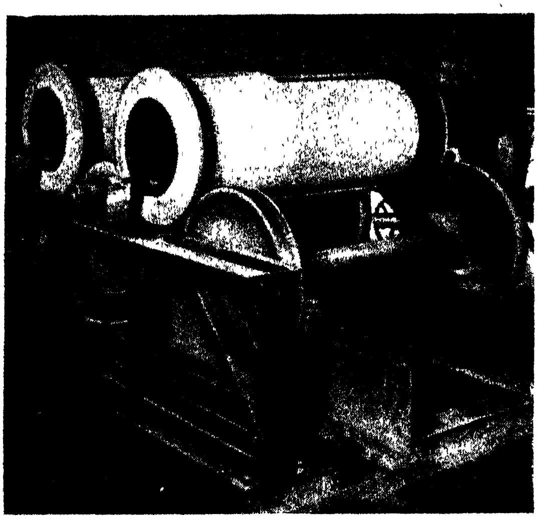


FIG 80. SPUN CONCRETE PIPES

FIG. 81. SURFACING CAST STONE WITH PORTABLE CARBORUNDUM DISC

Handling, Curing and Dispatch. Specially trained gangs will do all the handling and loading, but good supervision is required to prevent damage to the products, especially from the time when they leave the moulds until they arrive at the curing store. A great many devices are in use for transporting the freshly-made articles, and it is important that they should be stacked properly during curing, otherwise distortion and cracking may take place. The same precaution must be taken during curing as with cast-in-situ concrete. The products must not be allowed to dry out too quickly, especially when they are stored in the open during summer weather.

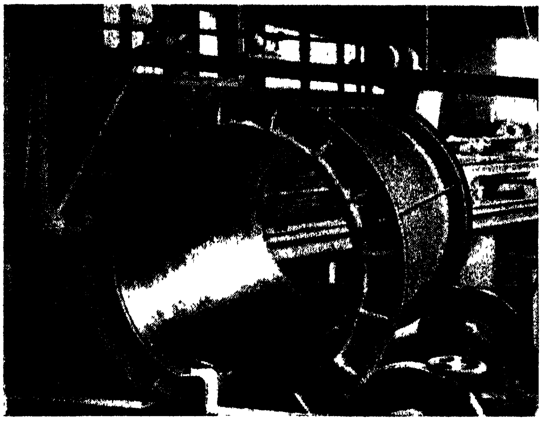


FIG. 82. SHOWING INTERNAL SURFACE OF SPUN CONCRETE PIPE

Some factories employ steam curing. In this method the products, as soon as possible after casting, are stored in chambers into which steam is admitted and the temperature gradually raised to about 120° F. This supplies a warm moist atmosphere which is ideal for curing concrete. After about 24 hours at the above temperature, the products are allowed to cool down and are then stacked in the open.

Light overhead cranes and small mobile cranes are usually employed for loading the articles into lorries or trucks for dispatch.

Works Maintenance and Stores. It is essential to have a good maintenance engineer and staff to attend to the plant and water supply, especially where a large amount of mechanical equipment is employed. A breakdown to one item of plant may cause a serious loss of output and disorganize the smooth running of the whole factory.

A good stock of spare parts for all machinery must be maintained so that repairs can be carried out with the least possible delay.

Figs. 74, 75, and 77 are included by courtesy of Concrete Utilities Ltd.
Figs. 80 and 82 by John Ellis & Sons, Ltd.
Fig. 79 by Liner Concrete Machinery Co.
Fig. 81 by Flextol Engineering Co., Ltd.

Land Surveying and Levelling

By Professor Henry Adams, M.Inst.C.E., F.R.I.B.A., F.S.I., etc.

Chapter I—INTRODUCTION

Application of Practical Geometry. Many books on land surveying begin with a series of problems in practical geometry. The advantage of this is that a surveyor first learns how to set up a true perpendicular by the aid of compasses only, instead of relying upon tee and set-squares, which may be untrue. It also shows him the true methods of copying angles and plotting triangles, and the method of reducing irregular figures to simple triangles. We can find room here for only a few of these.

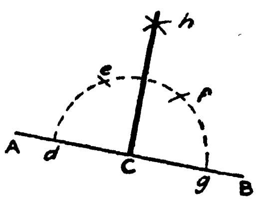


Fig. 1. To Erect a Perpendicular from a Given Point in a Straight Line

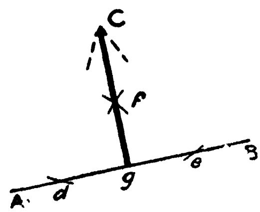


Fig. 2. To Let Fall a Perpendicular from a Given Point on to a Given Straight Line

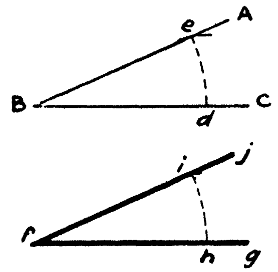


Fig. 3. To Copy a Given Angle

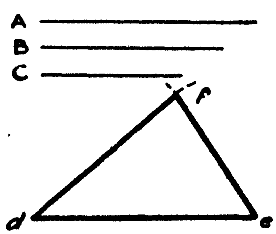


Fig. 4. To Construct a Triangle having Sides equal to Three Given Straight Lines

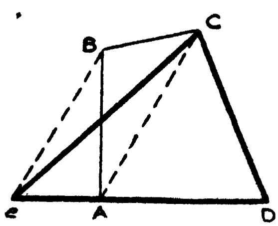


Fig. 5. To Make a Triangle equal to a Given Trapezium

1. From a given point in a straight line to erect a perpendicular (see Fig. 1). All verbal description can be saved by observing that the given lines are shown thin, the construction lines dotted, and the lines found by construction thick. They are also lettered in the order of construction, the given parts with capital letters and the construction lines with small letters, so that what may be called the "life history" of the problem is presented at a glance, and does not really require any further description to enable anyone to work it out.

2. To let fall a perpendicular from a given point on to a given straight line (see Fig. 2).

3. To copy a given angle (see Fig. 3).

4. To construct a triangle whose sides shall be equal to three given straight lines, any two of which must be greater than the third (see Fig. 4).

5. To make a triangle equal to a given trapezium (see Fig. 5). The given trapezium is shown at $ABCD$. The object is attained by converting two of the sides into two other sides which shall give an equal area and form with the remainder of the figure a single triangle. Let these two sides be AB, BC. Join their extremities by dotted line AC, and parallel to

this through B draw Be meeting DA produced in e. We know by Euclid that "triangles upon the same base and between the same parallels are equal," therefore triangle AeB is equal to triangle ABC, and the remainder of the figure being unaltered we have the triangle DeC equal to the irregular four-sided figure or trapezium $ABCD$.

Basis of Land Surveying. In land surveying the triangle is the basis upon which all work is carried out, and, generally speaking, the longest side should be treated as a base line upon which the remainder of the work is built up. The measurements taken on the land are recorded in a field book, and from these notes the work is "plotted," or transferred to paper, to produce a plan or map. If the land alone is concerned, whether for acreage or mapping, a 66-ft. chain divided into 100 links is used; but where building or constructional work of any kind is to be carried out, the 100-foot chain is preferable divided into 100 links, each 1 foot long. When a chain is spoken of, the 66-foot chain is usually intended.

Units of Measurement.

LINEAR MEASURE

7·92 in.[1]	= 1 link	12 in.	= 1 ft.
25 links	= 1 pole	3 ft.	= 1 yd.
4 poles	= 1 chain	$5\frac{1}{2}$ yd	= 1 pole
80 chains	= 1 mile	1760 yd	= 1 mile

[1] 66 ft. divided by 100 = 7·92

SQUARE MEASURE

625 sq links	= 1 perch	9 sq ft.	= 1 sq. yd.
16 perches	= 1 sq. chain	$30\frac{1}{4}$ sq yd.	= 1 perch
40 perches	= 1 rood	43560 sq. ft	= 1 acre
4 roods	= 1 acre	4840 sq. yd	= 1 acre
10 sq. chains	= 1 acre	640 acres	= 1 sq. mile

Every opportunity should be taken to test one's natural stride on the level, and up or down hill. Some can pace out a long distance in yards with great accuracy, but it is too long a stride for ordinary walking. The author prefers normal pacing. His standard is exactly 25 paces to the chain of 66 feet = 31·68 inches each pace = 2,000 paces to the mile.

The origin of the mile is said to be 1,000 double paces, which agrees with above; a league, or three miles, was the distance one could walk comfortably in an hour. The yard is the British standard of length; it is subdivided into feet and inches and multiplied into chains (66 ft.), furlongs and miles. Short distances may be given in feet and inches, or chains and links; long distances preferably in miles and furlongs or miles and chains.

The square measure used by land surveyors consists of acres, roods and perches, any small amount over being put as a fraction of a perch, $\frac{1}{4}$, $\frac{1}{2}$, or $\frac{3}{4}$, whichever is nearest. The usual limit of accuracy in practice is 1 perch per acre, so that any decimal points would be out of place.

Principles of Mensuration. A brief explanation of the principles of mensuration must be given before we can pass on to practical work. The area of any rectangular figure is found by multiplying the length by the breadth. Suppose we have a rectangular plot of ground 6 chains long and 2 chains wide, we find the acres, roods, and perches, thus—

$$\begin{array}{r} 6 \\ \underline{2} \\ 1,2 \\ \underline{4} \\ ,8 \\ \underline{40} \\ 32,0 \end{array} \qquad \textit{Ans.}, \text{ 1 a., 0 r., 32 p.}$$

As 10 square chains make 1 acre we divide the first multiplication by 10, or, in other words, mark off 1 figure; then multiply the remainder by 4 to bring it to roods, which leaves nothing on the left of the decimal point and shows no roods; then multiply the remainder by 40 to bring it to perches, and we find it leaves 32.

The area of a triangle when base and perpendicular are given is found by multiplying base and perpendicular together and dividing by 2. Suppose a triangular field with a base of 9 chains and a perpendicular from the opposite angle 4 chains long.

Then—

$$\begin{array}{r} 9 \\ \underline{4} \\ 2\,\overline{)36} \\ 1,8 \\ \underline{4} \\ 3,2 \\ \underline{40} \\ 8,0 \end{array} \qquad \textit{Ans.}, \text{ 1 a., 3 r., 8 p.}$$

When the three sides only of a triangle are given, the rule is somewhat complicated, but very important to be remembered. It is: *From half the sum of the three sides subtract each side severally, then multiply it and the three remainders together and take the square root for*

the area. Putting it down as a formula, we have—

$$\text{Area} = \sqrt{S(S-a)(S-b)(S-c)}$$

where a, b, and c, are the three sides respectively, and S is half their sum, or $S = \frac{a+b+c}{2}$. Suppose the sides of the triangle to be 5, 4, and 3 chains long respectively, then—

$$\frac{5+4+3}{2} = 6 \qquad \begin{array}{l} 6-5=1 \\ 6-4=2 \\ 6-3=3 \end{array} \qquad \begin{array}{l} 6 \times 1 \times 2 \times 3 \\ \quad = 36 \\ \sqrt{36} = 6. \end{array}$$

$$\begin{array}{r} 6, \\ 4 \\ \hline 2,4 \\ 40 \\ \hline 16,0 \end{array} \quad \textit{Ans.}, \text{ 0 a., 2 r., 16 p.}$$

In a four-sided figure with two sides parallel and perpendicular to the base, add together the parallel sides, multiply by the base and divide by 2. Suppose a field with two parallel sides $2\frac{1}{2}$ and 4 chains long respectively, and 6 chains apart, we have —

$$4 + 2\tfrac{1}{2} = 6\tfrac{1}{2},\ 6\tfrac{1}{2} \times 6 = 39,\ \frac{39}{2} = 19{\cdot}5$$

$$\textit{Ans.}, \text{ 1 a., 3 r., 32 p.} \qquad \begin{array}{r} 1,9{\cdot}5 \\ 4 \\ \hline 3,80 \\ 40 \\ \hline 32,00 \end{array}$$

Irregular four-sided figures are divided up into two triangles by drawing either diagonal, and then each triangle is calculated by one or other of the two methods given. All field measurements of lines should consist of not fewer than three figures such as 3·25, 1·17, 025, 004, with or without the decimal point, the last two figures always standing for links and the remainder for chains. Offsets are marked only by the necessary figures and all in links.

Measuring Simple Plot. The simplest case one can have in practical work is to measure a rectangular straight-sided plot, but it is not sufficient to measure round the sides and assume that the angles are right angles; the figure must be proved by measuring the two diagonals as well as the sides, as in Fig. 6. Sometimes, instead of the diagonals, tying triangles are measured across two adjacent corners as in Fig. 7, using not less than one-quarter of the length of the sides, as shown. The first triangle ties the figure and the second forms a check. The measurements are given in chains and links, but the decimal points may be left out, and then the same figures represent links of $12 \times \frac{66}{100} = 7{\cdot}92$ in. The measurements might also have been made in feet and inches if they had been taken with a 100-foot tape or chain. These examples should be plotted to a scale of, say, 1 inch to 1 chain.

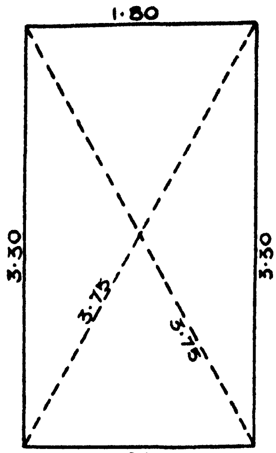


FIG. 6. SURVEY OF STRAIGHT-SIDED PLOT BY DIAGONALS

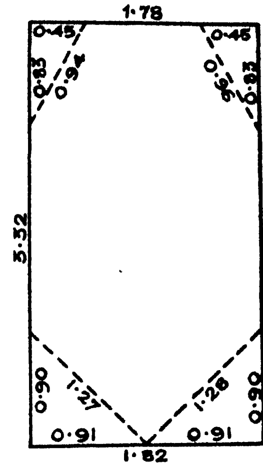


FIG. 7. SURVEY OF STRAIGHT-SIDED PLOT BY CORNER TRIANGLES

The Scales used in making survey plans differ somewhat from ordinary builders' scales, but they are easily understood. They are all decimal scales, that is, the unit distance is divided into 10 parts, so that a scale of 1 chain to 1 inch can be used equally well for 10 chains to 1 inch, or for 100 chains 1 inch. A so-called "universal scale" will be found very handy; each edge on each face has a double scale, 10·20—40·80—30·60—50·100. Special scales are made to suit the ordnance maps, and some also have chains on one edge and feet equal on the other. Offset scales are similarly divided to the larger scales, but are only 2 inches long and used as divided set squares. Plots of building land may be found with straight outlines such as we have already considered, although in nearly every case that a land surveyor is called upon to deal with the outline is more or less irregular, but he still bases his work upon the triangle, which is marked out in the field by "pickets" or "station poles." These are 6 ft. deal rods

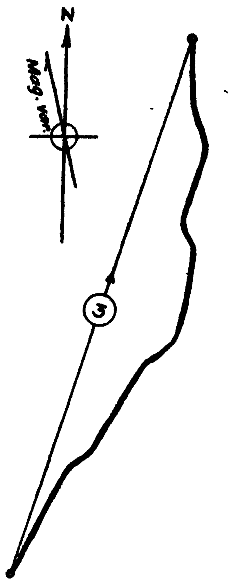


Fig. 8. Offset Piece

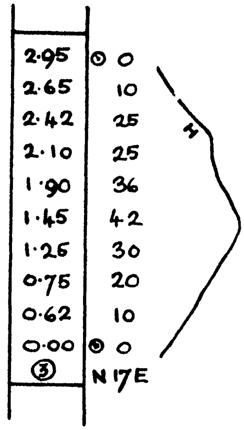


Fig. 9. Field Notes for Fig. 8

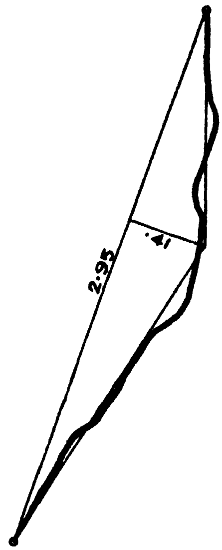


Fig. 10. Equalizing Line for Fig. 8

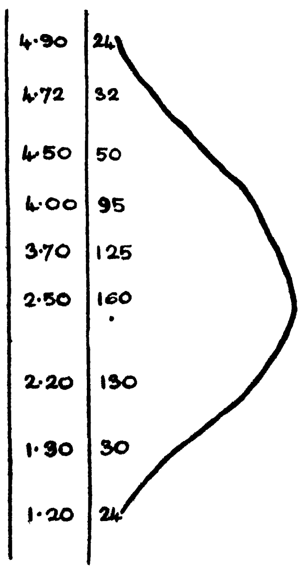


Fig. 11. Example of Long Offsets

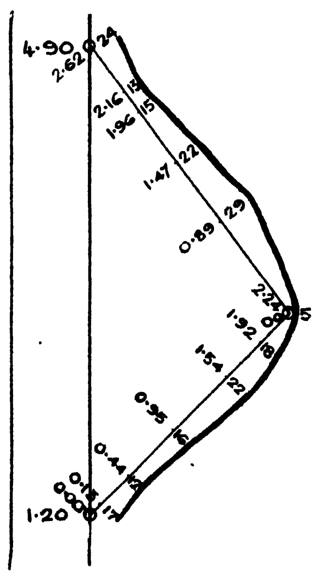


Fig. 12. Triangle to Avoid Long Offsets

with iron points and small flags at the top. The irregular strip between the line formed by two poles and the boundary is called an *offset piece*, and as that is an element of practically every survey, we will take one or two examples.

Chain Lines. In Fig. 8 the straight line represents one of the chain lines, the number on it shows that it is number three line, and the arrow head shows the direction in which it was measured. It is not convenient to put the measurements on the lines, and a *field book* is therefore prepared. A field book opens longways like a shorthand writer's notebook. There is a central line, or better, a central column, running down each page. The measurements on the chain line are put up the centre, working from the bottom upwards, so that the writer stands with regard to the figures the same way as the surveyor stands with regard to the chain.

On the right and left sides, the offsets or measurements to the boundary are put opposite the distances on the chain line where they occur, and on the proper side. Sketches are also made following the figures to show the lines or curves of the boundary, with letters indicating its nature, *H* for hedge, *D* for ditch, *F* for fence, *W* for wall, *Fp* for footpath, etc.

North Point. The direction of the *first line* is given by comparison with a pocket compass, remembering that the magnetic variation alters from year to year, and that at present the needle points about 11 degrees west of true north. It changes altogether 25 or 30 degrees east and west of true north in the course of about 160 years, and is at the present time getting nearer to the true north at the rate of about 5 or 6 minutes per annum. It moves rather slower as it gets near the true north, which it will pass and will then lean towards the east. To avoid any mistake, the true north point and the magnetic variation should be shown upon every survey plan.

The true north can be ascertained approximately by pointing the hour hand of a watch to the sun, bisecting by the eye the angle between that direction and 12 o'clock, and carrying the line backwards. If the minute given by this line be noted and also the minutes indicated by the direction of the chain line, then six times the difference in minutes can be plotted as the angle in degrees made by the chain line with true north. The directions of other lines after the first are obtained by the intersection of their lengths to form triangles. For Fig. 8 the field book will be as shown in Fig. 9, the station poles being indicated by a circle with central dot. The direction is shown as 17 degrees east of true north.

Area of Offset Piece. The area of an offset piece can be obtained by using equalizing lines to form a triangle and then measuring base and perpendicular, as in Fig. 10. Then the area will be—

$$
\begin{array}{r l}
2{\cdot}95 & \\
{\cdot}41 & \\
\hline
295 & \\
1180 & \\
\hline
2\,|\,1{\cdot}2095 & \\
\hline
{\cdot}60475 & \quad\textit{Ans} \\
4 & \quad 0\text{ a., }2\text{ r., }16\tfrac{3}{4}\text{ p.} \\
\hline
2{\cdot}4190 & \\
40 & \\
\hline
16{\cdot}7600 &
\end{array}
$$

This offset piece should be plotted for practice to a scale of, say, 1 inch to 1 chain. By laying the 12 inch scale down with the zero corresponding to the zero of the chain line, and using the offset scale as a set square, the offset distances can be pricked off very rapidly and the boundary drawn through.

Offsets should, as a rule, never exceed one chain in length; if they would do so when measured direct, as in Fig. 11, it is usual to take them by means of a triangle based on the chain line, as in Fig. 12. This is done owing to the difficulty of judging true perpendiculars from the chain line by the eye. It is not necessary to take the area of each offset piece separately. Equalizing, or "give-and-take," lines may be run round the whole boundary and joined up into triangles across the interior, summing up the results of base by perpendicular and not forgetting the dividing by 2. All the triangles of a survey should be "well-conditioned," that is, they should have no angle less than 30 degrees, or more than 120 degrees.

Chapter II—SURVEYING INSTRUMENTS—CHAINING

Field Work in Surveying. It is now time to consider the actual work in the field. The usual complement of apparatus is *chain and arrows*, *pocket compass*, *station poles*, and *offset staff*. The chain and arrows are shown in Fig. 13, where the chain appears at *a* as done up ready for carrying away; at *b* is shown one end and exactly how a link is measured; at *c* is shown an intermediate portion of the chain with one of the brass *tallies* which are attached at every ten links. These tallies indicate to the surveyor at what part of the chain he is standing, so that he only has to count the odd links up to the ten he is nearest to. A single-pointed tally indicates 10 or 90 links; two-point, 20 or 80 links; three-point, 30 or 70 links; four-point, 40 or 60 links; and a round tally, 50 links. When done up the chain links should lie slightly diagonally, touching at their centre and the tallies hanging out. There are 10 arrows as at *d* accompanying the chain, with a little white or red flag on each so that it can be distinguished readily on the grass. Any ordinary pocket compass is generally sufficient to give the direction of the base line, but in important work special care must be taken to get the true meridian. The station poles are of fir, painted in portions alternately red, white, and black, with pointed steel shoes for driving in the ground, and a flag about 12 in. square nailed to the top. The flag is half red and half white to show up well in the distance. The offset staff is like a larger station pole; but the divisions, black and white only, are exactly one link each, ten in all; a narrow red ring painted on marks the centre. Instead of a flag at the top the termination is made by a flush hook, for use in pulling the chain through a hedge when necessary.

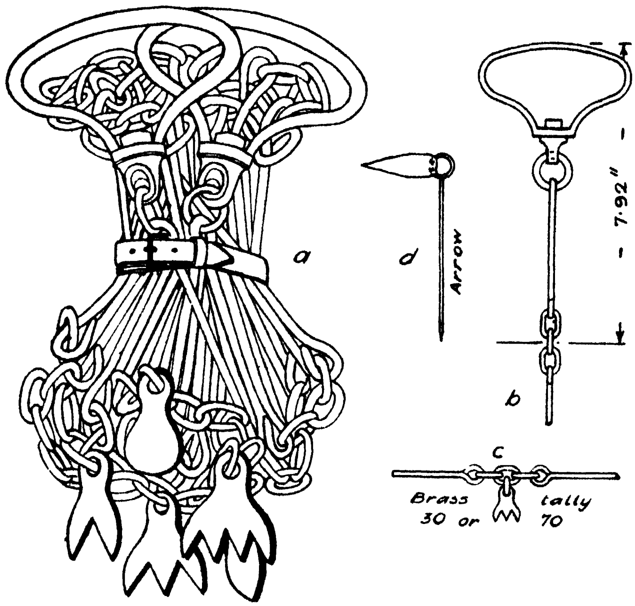


Fig. 13. Chain and Arrows

Studying the Work. Before starting a survey the surveyor walks over the ground and considers the best position for the lines, and generally makes a small sketch of them in his field book, numbering them in the order he proposes to measure them. At each point where the stations, or ends of lines and expected junctions of lines, occur the surveyor takes a pole, and, holding it lightly but firmly, drives it upright into the ground. It requires practice to do this neatly and effectively. He then takes the bearing of the base line. Not only must the field be measured out in triangles, but all the triangles must be so tied by lines crossing them, or otherwise that they are fully checked. Fig. 14 shows some typical arrangements of the main lines of a survey which mutually tie and check each other. This means that if a mistake is made either in measuring or plotting it is bound to be discovered, as the lines would not properly join up.

Method of Chaining. The surveyor is accompanied by a *chainman* to carry the poles, etc., and assist him in his work. Having removed the strap from the chain, the surveyor keeps hold of the two handles and throws the chain out, so that it lies double on the ground from the 50 tally to the handles, in the direction of the first line, preferably the base line. He then passes the arrows and one of the chain handles to the chainman, who walks forward in the

direction of the line, taking care to keep the one side of the chain clear from the other. Then, holding one of the arrows vertically against the outer edge of the handle, with his thumb through the ring, he faces the surveyor, stoops down, and watches for signals. All signals should be by motion and not voice. Sighting past the chainman to the distant pole the surveyor

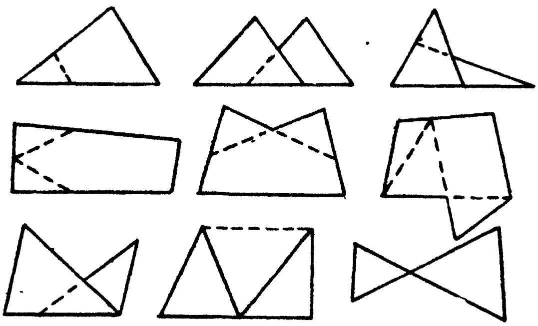


FIG. 14. TYPICAL CHAIN LINES TIED AND CHECKED

signals right, left or down, by moving only his hand, not his arm, in the required direction. The arrow being inserted, if any offsets are required they are now taken and entered in the field book. The position on the chain line is decided, and the length of a short offset measured with the offset staff. If the offset is long, the offset staff is laid down against the chain at right angles and then passed "hand over hand" to the offset point, which must be kept in view all the time to ensure a true measurement.

Boundaries. Where the field is surrounded by a hedge and ditch, the brow of the ditch is usually the true boundary, and as this is often more or less broken away, it is customary to allow 5–10 links from the centre of the hedge which is easier to measure from; say, five links between fields belong to the same owner, 6–7 links when belonging to different owners, and 7–10 links when abutting on public lands. It is often said that the reason the owner's boundary is the brow of the ditch on the farther side of the hedge is because, in digging the ditch, he must not throw the earth on his neighbour's land and, therefore, uses it to form the bank upon which he plants his hedge. The true reason is that it is a survival of the old custom of constructing a wall and moat. When an enclosure is shut in by a fence the face of it is the true boundary, so that the owner looks on the back, or as they say, in making the fence the nails are driven "home."

There are certain signs used in the field book and on the plans in connection with the boundaries, as shown in Fig. 15, where the *T* shows the side the fence or hedge belongs to; the brace or long *S* shows that the area of the small enclosure or building is taken along with the larger area, and the dumb-bell shows a change of boundary, such as the ditch changing to the opposite side of the hedge.

When the first chain length is disposed of, the chainman takes up his end of the chain and goes forward again. Upon reaching the first arrow, the surveyor verifies the direction of the chainman, who now puts down the second arrow while the surveyor takes up and retains the first, and so the work is continued.

In surveying long lines, when the whole ten arrows have been inserted, the chainman calls "tally"; the surveyor comes up, draws the final arrow, puts his toe on the place, counts all the arrows, and then hands them to the chainman. As the end of each line is reached in the field book a line is drawn across the centre column, and when a triangle is completed some surveyors make this a double line, indicating that

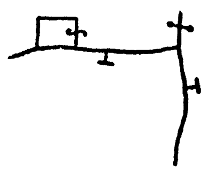


FIG. 15. BOUNDARY MARKS ON PLANS

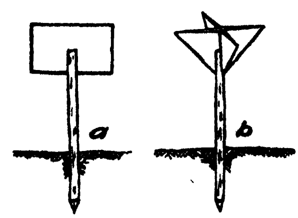


FIG. 16. WHITES FOR MARKING SUBSIDIARY POINTS

they can plot the work so far. When the whole survey is completed, a horizontal line is drawn right across the page. All the entries may be in pencil, but ink is better because more permanent. Subsidiary lines in a survey may be marked by "whites" to save poles, made by inserting a slip of paper in a twig with a single slit (*a*) or a double slit (*b*), as in Fig. 16.

Chapter III—SURVEYING

Survey of Triangular Plot. Fig. 17 shows a survey that was made of a plot of grass land on the top of Primrose Hill, London. It is inserted to show that when circumstances permit, the chain line may cross and recross the boundary, which it could not do with a hedge or fence. It

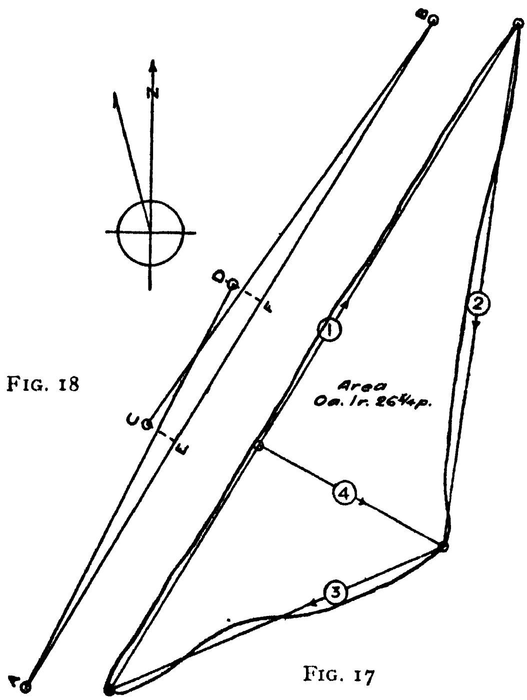


FIG. 18

FIG. 17

FIG. 17. PLOT OF GRASS LAND WITH CHAIN LINE CROSSING BOUNDARIES

FIG. 18. PLAN OF POLING OVER HILLY GROUND

was also notable from the fact that on line 1 the ground rose in the middle, so that the station pole at one end could not be seen from that at the other end. By the surveyor and his assistant taking two poles *C* and *D*, Fig. 18, and standing between the extremities *A* and *B*, each can see the pole at the further end and direct the other into line, step by step alternately, until they reach *EF*. The line can then be chained through from either end as may be needed. Fig. 19 gives the field notes for this survey.

Complete Survey. An example of a complete survey will now be given. Fig. 20 gives a sketch of the chain lines, Fig. 21 the field notes, and Fig. 22 the finished survey plan. It will be seen that the notes should commence with the name of the place and date, and the bearing of the

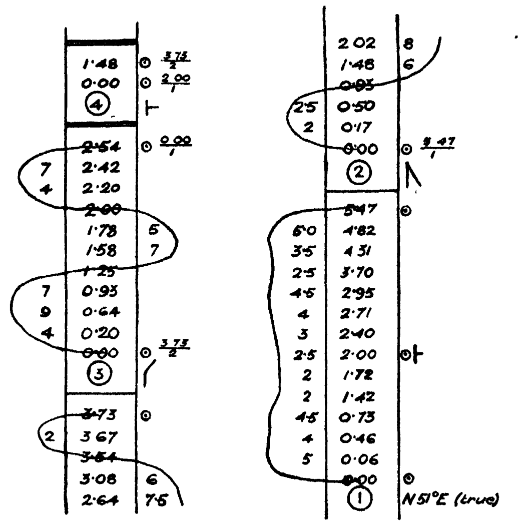


FIG. 19. FIELD BOOK FOR FIG. 17

first line, either true or magnetic. Sketches of the boundaries and junctions are made at each side beyond the offsets; then the first line should be measured and entered.

In commencing a new line, a mark like a signal post is made to show by the upright part the old line from which the new one starts, and by the signal arm the approximate direction of the new line. This will be found of great assistance in the plotting, and is better than the old method of inserting a note "Go right," or "Turn to right," or to left, as the case may be. This only gave two possible directions, while the signal post can give eighteen, as will be seen from a close study of Fig. 23. Then against the first station on the new line a fraction is shown like $\frac{4{\cdot}90}{1}$, to indicate that the station was first reached at a distance of 4·90 on line 1. No difficulty should be found in plotting this survey.

The note " line × " at 5·15 on (2) and elsewhere is inserted in the field book as a help in plotting the survey, showing where other lines cross.

It frequently happens, that the exact crossing of the line cannot be determined until later, as it would require both the lines to be sighted through at the same time to a pole at the junction. In such a case the approximate position is first noted, and then when the other line is chained the exact crossing may be noted in the offset column of the new line as " back 3 from $\frac{5\cdot15}{2}$," or as the case may be. The lines may be set out in the order in which they are numbered, marking carefully the junction points on lines 2 and 3, and then seeing that the check line 8 crosses with all the distances exact after having made any necessary corrections as suggested above.

True north should, whenever possible, be

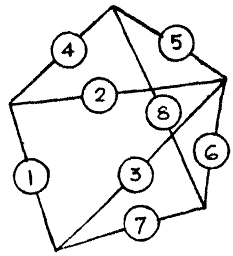


Fig. 20. Sketch of Chain Lines for Survey

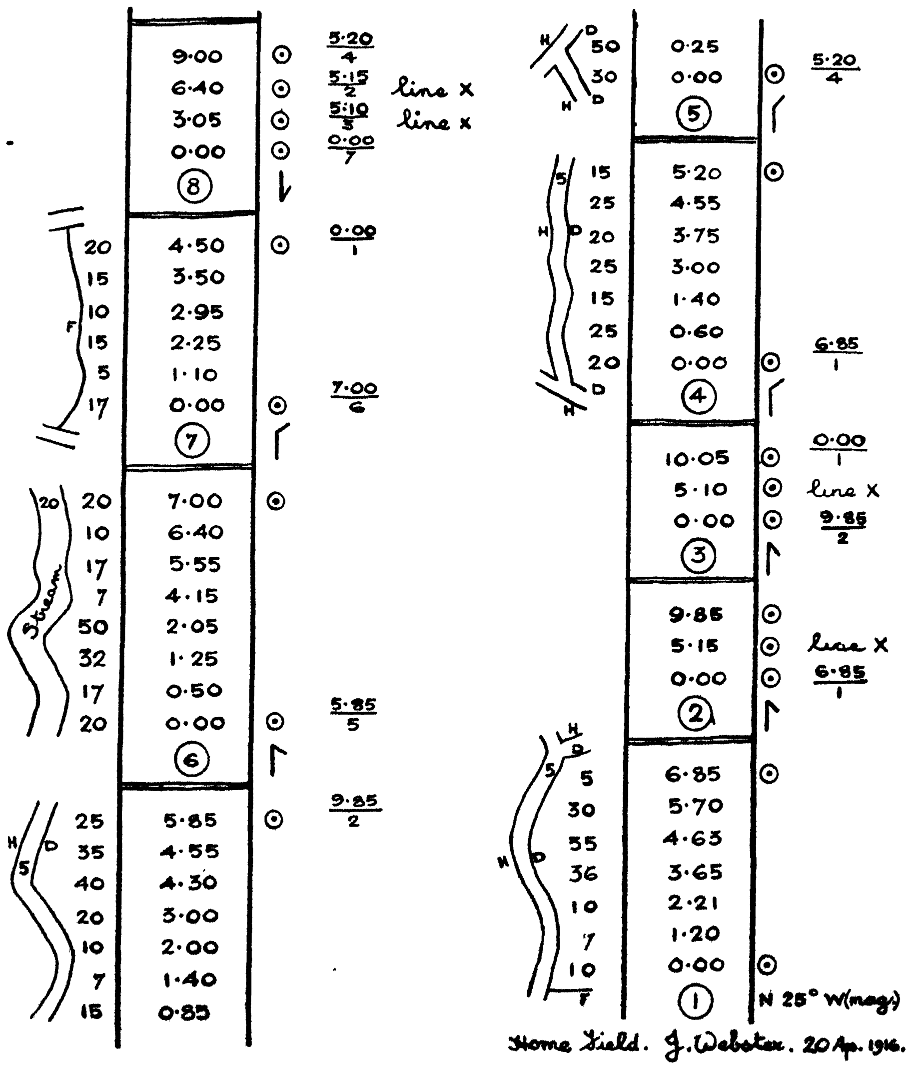


Fig. 21. Field Notes for Fig. 22

pointing vertically upwards on the paper, the survey plan being adjusted to suit this. The angle from the magnetic north may be noted in the field book, and reference made to *Whitaker's Almanack* to know the magnetic variation for

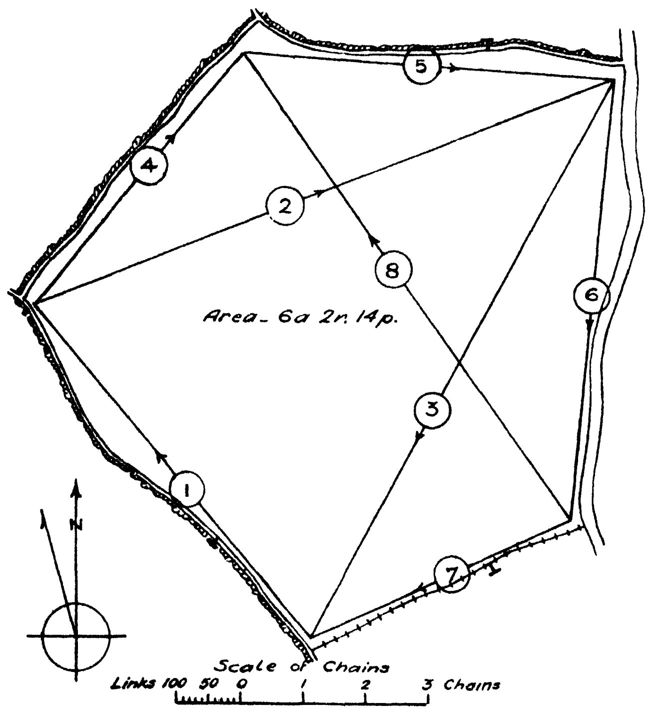


FIG. 22. SMALL COMPLETE SURVEY

the year, to enable the true north to be shown on the survey plan.

Hedges on Plans. Upon small scale plans the hedges are usually shown by plain lines, but on a larger scale freehand representations of the bushes forming the hedges are often shown, as in Fig. 24. Trees, where measured for position, are shown in plan as in Fig. 25, with a small cross for the actual spot.

The scale should at least be stated in words and preferably drawn also, upon every survey plan. Sometimes it is useful to have "Feet equal" marked also. Thus a scale of chains may be drawn with the divisions marked above the line, and a scale of feet with the distances in 100 ft. lengths marked below the line. Tithe and parish maps are usually to a scale of $\frac{1}{2376}$ = 3 chains to 1 in., which gives nearly one acre to the square inch.

Land surveying cannot be learnt from books alone; every opportunity should be taken for actual practice in the field, as it is the only way to realize and surmount the difficulties that arise from time to time.

Surveying Outside a Boundary. Lakes and woods can be surveyed by the chain if the lines be run outside the boundary. They must be sufficiently tied, but can

FIG. 23

FIG. 24

FIG. 25

FIG. 23. TYPICAL DIRECTION MARKS IN FIELD BOOK FOR LINES JOINING

FIG. 24. ENLARGED SKETCH OF HEDGE FOR SURVEY PLANS

FIG. 25. SKETCH OF TREE, THE CROSS MARKING POSITION

hardly get so good a check as a field with outer boundaries, where the chain lines can all be put inside. Without giving the field book, it will be enough to show the chain lines for two such surveys with the features sketched in. Fig. 26 shows the lines used for a lake, and Fig. 27 the lines for a wood. Representations of trees may be shown in the survey of the wood, but it is essential to bear in mind the scale. The writer once saw the survey of an ornamental lake, shown with some ducks and patches of bullrushes. One of the ducks scaled two chains long through inattention to the above note. A magnified view of the conventional forms given to the trees and bushes by surveyors is shown in Fig. 28. An elm may be 60 ft. high, other trees 30 ft. to 40 ft. Stencils of trees may be purchased if the surveyor mistrusts his skill in sketching.

Scales Used. A common scale for land surveyors is 1 in. to 1 chain, but for building plots it is rather small, being 66 ft. to 1 in. Engineering surveys with a 100 ft. chain are often plotted to 40 ft. to 1 in. It is a pity the ordnance scale of 41·66 ft. to 1 in. was not made 40 ft.; engineers have to sacrifice their convenience so that the Ordnance Survey Department might use a scale of $\frac{1}{500}$ instead of $\frac{1}{480}$. It may be

useful to give a list of the various scales to which ordnance maps are drawn—

$\frac{1}{63360}$ = 1 in. to a mile, is known as the small scale.

$\frac{1}{10560}$ = 6 in. to a mile, is the medium scale.

$\frac{1}{2500}$ = 25·344 in. to a mile, is the large scale.

$\frac{1}{1056}$ = 5 ft. to a mile = 88 ft. to an inch, is a special scale for towns.

$\frac{1}{528}$ = 10 ft. to a mile = 44 ft. to an inch, is the larger scale for towns.

$\frac{1}{500}$ = 10·56 ft. to a mile = 41·66 ft. to an inch, is the new ordnance scale for towns.

The first of these is very useful for county maps, but hardly large enough for marking the sites of estates. The second one is the most generally useful for transferring portions to serve for site maps. The 5 ft. and 10 ft. scales will in many cases give the required plots and boundaries, but it is always wise to test them on the

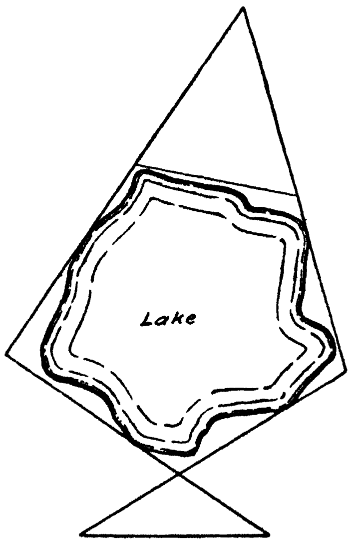


FIG. 26. SURVEY OF LAKE

ground. In addition to marking the scale upon a survey plan, the area should be shown on the centre of each plot, or a table made at the side where the separate enclosures may be listed and the total made up.

Copying Plans. Portions of an ordnance map may be traced off, provided a licence is obtained and the fee paid, and then transferred to another plan by carbon paper. Copies of plans to scale may be made in black lines on a white ground by means of photo-printing. An enlargement may be made by ruling the required portion with small squares by lines, say $\frac{1}{8}$ in. or $\frac{1}{4}$ in. apart, then ruling lines on the required drawing, as much farther apart as the plan requires to be enlarged. The outlines may then be put in by hand, noting at what distances they cross

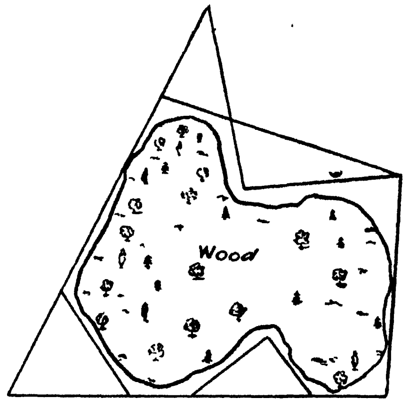


FIG. 27. SURVEY OF WOOD

the respective lines. Proportional compasses may be used to give these distances exactly if great accuracy is required. An instrument, called a *pantograph*, may be used for enlarging, but it is not worth while, as the method of squares is perfectly satisfactory; the *eidograph* is a still more expensive instrument for the same purpose. Suppose the enlargement required be from the 25·344 ordnance map (usually called the 25 in.) to a scale of 20 ft. to 1 in., then squares of $\frac{1}{4}$ in. side on the ordnance

FIG. 28. ENLARGED SKETCHES OF TREES AND BUSHES ON SURVEY PLANS

map would be replaced by squares of, say, 2·6 in. sides on the survey plan.

Calculated thus—

$$\frac{5280 \times \frac{1}{4}}{25{\cdot}344 \times 20} = 2{\cdot}604$$

The size of the squares on the ordnance map will depend upon the amount of detail shown, but $\frac{1}{8}$ in. to $\frac{1}{4}$ in. is most usual.

Obstructions

Gaps and Detours. A surveyor may occasionally have to make a detour round an obstruction in running a chain line. There are two principal

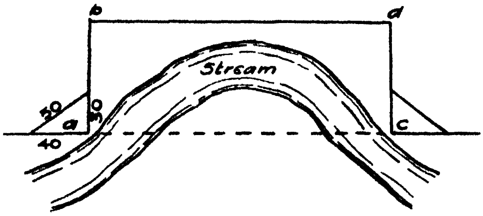


Fig. 29. Chaining Round an Obstruction that can be Seen Over

cases: (*a*) when the obstruction can be seen over, as the bend of a river; and (*b*) where the view is totally obstructed, as by a house or a haystack. Of course, the lines should be laid so as to clear all obstructions so far as may be

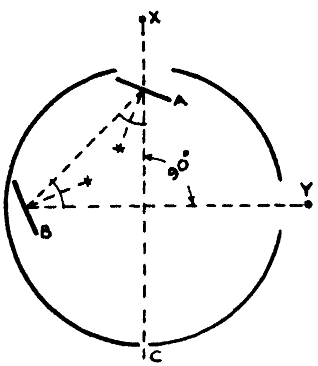


Fig. 30. Construction of Optical Square

possible, but there are many cases where they cannot be avoided. The base line should be the longest available on level ground, as the accuracy of the survey will greatly depend upon it; where, however, proper check lines are taken, there cannot be any great error. Fig. 29 shows how the chain may be carried past the bend of a stream. The chain line is sighted through from end to end, a pole being placed at *a* and another at *c*; it is required to know the distance from *a* to *c*. Set up a right angle with the chain at *a* by measuring back 40 links on the chain line; peg one end of the chain down at this point and the 80th link at *a*. Then take hold of the 50 tally and gently straighten out the two sides of the triangle. The 30 side is then to be produced to *b* far enough to clear the obstruction. A similar triangle must be set up at *c*, and *cd* made equal to *ab*, then *bd* will be the length of the omitted portion from *a* to *c*. Suppose up to *a* the chain line measured 4·32 and *bd* measures 1·12, then *c* will read 5·44. Offsets to the stream should be measured and entered on a sketch in the field book. A right angle set up by the chain cannot be depended upon nearer than one quarter link, and an optical square is sometimes used for the purpose.

Optical Square. The arrangement of the optical square is shown in Fig. 30, where *A* is a glass, silvered half-way up and left plain for the other half, set at an angle of $67\frac{1}{2}°$, with the line of sight *CX* along the chain line. *B* is a

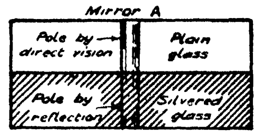


Fig. 31. Reflecting Mirrors in Optical Square

wholly silvered glass, set at $67\frac{1}{2}°$ to the transverse line *BY*. Then, sighting along the chain line through *C*, the distant pole will be seen through the unsilvered portion of *A*, and a pole held by an assistant in the direction *BY* will first be reflected by the mirror *B*, and then into the silvered portion of *A*. When an exact right angle is obtained, the two portions of pole will appear superposed as in Fig. 31.

OBSTRUCTED LINES. Fig. 32 shows the method of procedure when the forward view of the chain line is wholly obstructed. The distance *ab* must be twice that of *bd*; perpendiculars are set up as before, and the distance *cd* checked until it is made equal to *ab*; then the two diagonals of the parallelogram must be measured and made equal. This ensures that the line *cdef* will be parallel to the chain line. From *ab* the same operation is gone through in the opposite direction, so as to make a true continuation of the chain line at *gh*; the distance *dc* will then be equal to the omitted length *bg*.

A quarry, gravel pit, or small lake may be surveyed by setting up two triangles with a common apex as in Fig. 33. From *b*, on the chain line *abc*, a line is run to clear the pit and continued so that *de* is equal to *bd*; from *c* through *d* a line is continued to *f*, making *df* = *cd*. Then, whatever the angles may be of the two triangles, the length *ef* will be equal to the omitted length *bc*.

Rivers. There are some half-dozen methods of finding the width of a river by the chain, so that a line may be continued across it. The

simplest method is shown in Fig. 34, where the points *a*, *b*, and *c* are in one line. A right angle being set up at *b*, any distance *bd* is marked

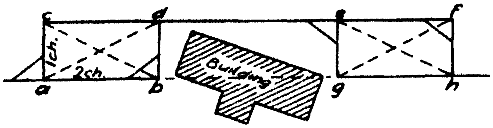


Fig. 32. Chaining Round an Obstruction when it Cannot be Seen Over

off and continued to *e*, so that $dc = bd$. Another right angle is set out at *e* and continued to any point *f*; then, with poles at *c*, *d*, *e*, and *f*, the surveyor walks backwards, keeping *dc* and *fe* in view until they all coincide at point *g*. The distance *ge* being measured, will give the required distance *bc*. Some of the textbooks say look out for a white stone, tree trunk, or something else to sight to on the far bank of the river, but there may be difficulty in seeing it from *g*; and apart from this, if *abc* represent a chain line, it

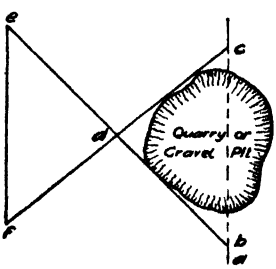


Fig. 33. Passing Gravel Pit by Double Triangle

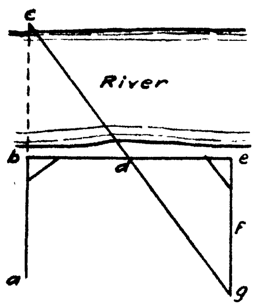


Fig. 34. Finding Width of River

will be necessary to get across the river some time or other, and therefore a pole should be planted at *c*. Where a stream is under one chain wide no construction of this kind will be necessary, as the chain can be held across it. The reading of the chain up to the near bank with the width of stream added to it, will give the reading to continue from on the far bank.

Surveying on Hilly Ground

Measuring on Sloping Ground. In measuring lines on sloping ground allowance must be made for the slope. If *AB*, Fig. 35, represents the surface of the ground, and *CB* the rise in the horizontal distance *AC*, the length measured will be *AB*, but the length to be plotted will be *AC*. The inclination may be obtained by a *clinometer* of one or other of the various patterns; and the horizontal length, or cosine, calculated by the use of tables; but the true length may be obtained by the chain only, which is by far the most convenient method and sufficiently accurate for ordinary purposes. Fig. 36 shows how this is done. The 50 tally being held on the ground by an assistant, the

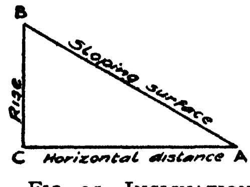


Fig. 35. Inclination of Ground

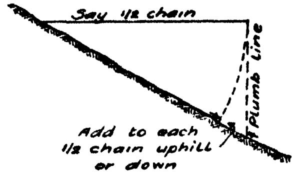


Fig. 36. Finding Correction for Chain Line on Sloping Ground

surveyor holds up the end of the chain until he judges it to be horizontal, and uses a plumb line to find the true horizontal distance. He then lays the handle of the chain on the ground, as shown by dotted curve, and measures the distance that each half chain must be pulled

Angle	Correction per Chain
4 degrees	¼ link
6 ,,	½ ,,
8 ,,	1 ,,
10 ,,	1½ ,,
15 ,,	3½ ,,
20 ,,	6½ ,,
30 ,,	15½ ,,

forward to give the true length, whether going up or down hill. The whole chain could not be held out, because its weight would cause it to sag too much. A beginner may have some difficulty at first in understanding why the chain requires to be pulled forward, since the slope is longer than the horizontal; also, why there is no difference made in going up or down hill. He is advised to study Fig. 36 to get clear on these points. The correction for different angles will be as shown in the table above.

When the slope is sufficient, hilly ground may be indicated on plans by shading, as in Fig. 37, the same as mountains are shown on maps. The strokes should be slightly waved, thicker and closer towards the highest part, and broken off irregularly so as not to show radial lines,

which would spoil the effect altogether. This, however, is only pictorial, and a much more satisfactory method is to show *contour lines* at given heights, as in Fig. 38, where the contours for a hill are shown with sections through the flattest and steepest portions.

Stepping with the Chain. The horizontal distance on a slope is sometimes obtained, or supposed to be obtained, by "stepping" with the chain, as shown in Fig. 39. An arrow is dropped head downwards to mark the point where a plumb line would fall. It is an objectionable method, and so rough and unreliable that the writer has known cases where the horizontal distances came out longer than the slope. By the first method described more care is taken, as it is done once for all and the true allowance ascertained for each chain length, so long as the slope remains uniform. It requires practice to judge of a slope without measuring it; the tendency is to overestimate the angle of a slope in degrees, and to underestimate the difference of level between any two points.

FIG. 37. HILL SHADING

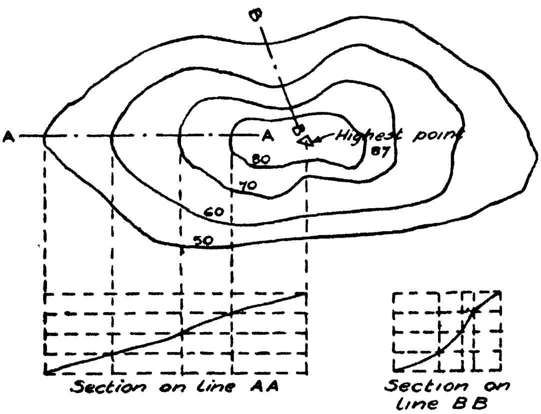


FIG. 38. CONTOUR LINES AND SECTIONS

It should be noted that land is bought and sold by horizontal area, and that in mapping only horizontal areas can be shown. Although the earth is round, any portion that a surveyor measures is practically flat, the rise of curvature in a mile being only 4 in., except as regards any local prominence. It has been suggested that if the earth be likened to an orange, the roughness of the peel would be sufficient to represent the mountains.

Contour Lines. There are various methods of obtaining contour lines; one of the simplest is to range a series of lines across the given area, or to converge them to one point, as in Fig. 40, which is a repetition of Fig. 38. The surrounding stations being chained for plotting, then by the use of a level the surveyor finds on each of these lines points at the required vertical heights, which can be marked by whites *a*, *b*, *c*, *d*, *e*, *f*, *g*, etc. While the level is set up, he can also turn the telescope right or left, and signal to an assistant holding the staff, half a chain or so away, to move up or down the slope, as the case may be, until the staff reads the same as on the radial line. Any number of intermediate points between the radial lines may be thus obtained and marked by whites, to be afterwards surveyed by the chain as offsets from straight lines between the points *af*, *bg*, etc.

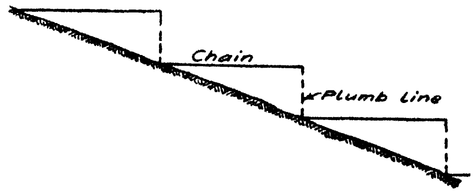


FIG. 39. STEPPING WITH THE CHAIN

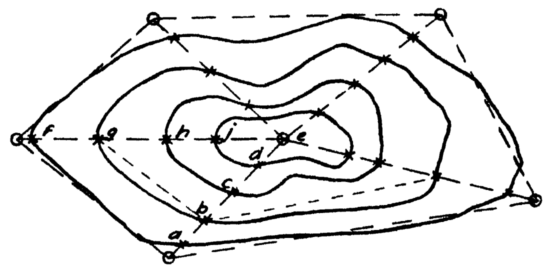


FIG. 40. SETTING OUT CONTOUR LINES

Hand Reflecting Level. A hand reflecting level may also be used to get the intermediate points on a contour line. It is shown in longitudinal and transverse section in Fig. 41. There is a metallic mirror occupying half the width of tube, and a wire or horse-hair crossing the centre of tube. A hole in the top allows the

bubble of a spirit level to be seen at the same time. In using this level, the surveyor takes it in his right hand, sights through to a staff held on the starting-point, and takes the reading

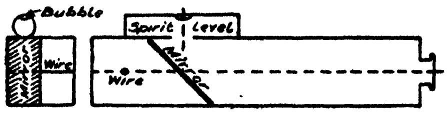


FIG. 41. HAND REFLECTING LEVEL

when the line engraved across the centre of mirror cuts the reflection of the bubble equally. Although used without a stand, this level will give results within about half an inch as the surveyor holds it to the height of his eye each time. There are no lenses in the hand reflecting level, and it can therefore only be used for short sights.

TRAVERSE SURVEYING

Traversing with Chain, etc. *Traversing* is another method of surveying, by which a road or river may be mapped by a series of chain lines, the angles at the junctions being taken by a prismatic compass, box sextant, theodolite, or, more roughly, by the chain alone. In the latter case

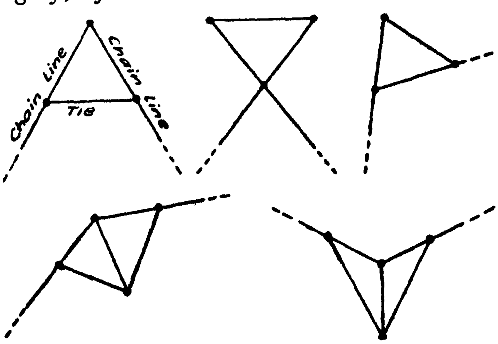


FIG. 42. JUNCTIONS OF LINES IN TRAVERSING WITH CHAIN

the junctions will be tied by small triangles, but there will be no check upon the work. Examples of tying the ends in this way are shown in Fig. 42. The lines may be ten or fifteen chains long, if necessary, but the sides of the triangles need not be more than one chain long. In plotting, greater accuracy will be obtained if the triangles are drawn to double the scale of the lines, allowing the proper length of each line between the stations.

Prismatic Compass. The prismatic compass is a handy little instrument for giving the direction of the lines in traversing, so that they may be plotted from the compass bearing. Fig. 43 shows the general appearance, Fig. 44 a section through it from front to back, and Fig. 45 the plan. The prism deflects the rays of light from the card to the eye; the card is

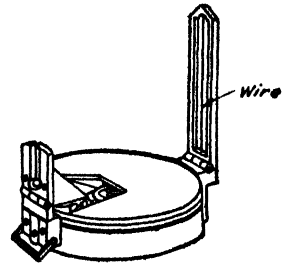


FIG. 43. SKETCH OF PRISMATIC COMPASS

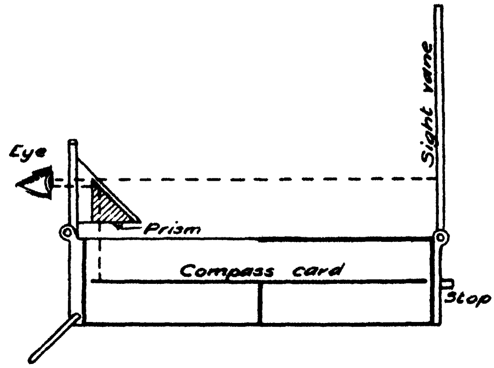


FIG. 44. SECTION OF PRISMATIC COMPASS

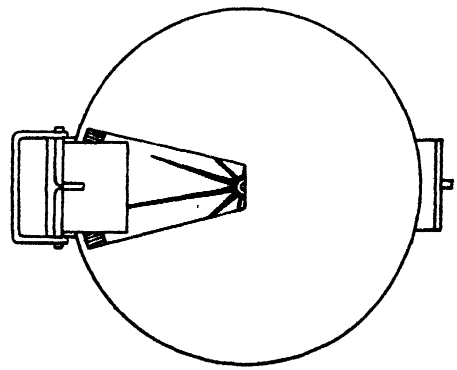


FIG. 45. PLAN OF PRISMATIC COMPASS

attached to a compass needle below it, but the north point of the card is over the south end of the needle, because the surveyor is reading at the south end when the needle is pointing north. The degrees are marked 0 to 360 to read east of north. Care must be taken, when using the prismatic compass, not to be near iron railings, which would deflect the needle;

sometimes even a water main below the ground will have this effect. To guard against errors due to this cause, the reverse bearing should be read from the other end of the line, and the difference should be 180°. The direction is obtained by sighting through the prism past the wire, or horsehair, up the centre of the hinged arm. The eye can at the same time see the figures on the card, and read where the line appears to cut. A stop is provided at the back to check the oscillations, and if the hand is unsteady a stick may be used to rest the compass upon.

Terms Used in Traversing. There are certain terms used in traversing that must be explained. "Meridian lines" are lines lying due north and south, and differ from the meridian lines on a globe by being assumed to be parallel. By the "bearing of a line" is meant the angle made by it with a meridian line. This is measured either by degrees clockwise from the north point, or by degrees up to 90 east or west of north or south, according to the quadrant in which it lies, and depending upon the way in which the compass card is marked. The "difference of latitude," or the "northing and southing," is the distance the end of the line is farther north or south than the beginning. The "difference of longitude," or the "departure" of a line, is the distance the end is east or west of the beginning. The "meridian distance" of any station is the distance east or west of some previous point, such as the first station. When the lines are zigzag, any station may be indicated by its meridian distance and difference of latitude. These terms are illustrated in Fig. 46.

It will be observed that the latitude and departure are the same as the sine and cosine in trigonometry, and trigonometrical tables may be used instead of traverse tables for the plotting.

Open and Closed Traverses. A traverse may either be "open" or "closed"; the former when the plotted lines make an open figure, and the latter when they continue until the starting point is again reached. An accomplished surveyor must know all about traversing, and the use of traverse tables or tables of sines and cosines, but for ordinary purposes this knowledge is not essential. It is good practice for a student to make a closed traverse survey in a large field and then plot it on paper. If able, he should calculate the northings and southings, eastings and westings, when the pairs should agree; but he may take some comfort from the fact that they never did agree yet in practical work, the average closing error being about one-quarter link per chain of the total

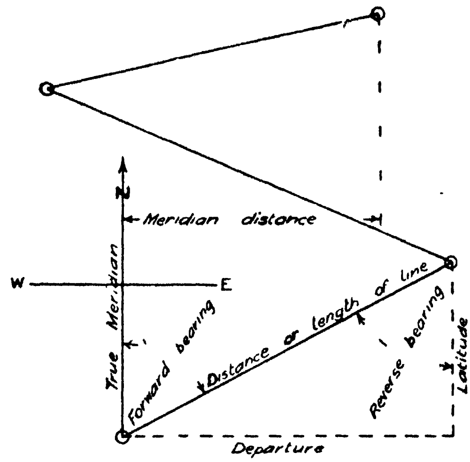


FIG. 46. ILLUSTRATION OF TERMS USED IN COMPASS TRAVERSING

measurements. There are recognized means of correction for closing errors, but they lie rather beyond the scope of this section. The errors may be due to the lines or the angles, or both, but more probably the angles will be in fault unless a theodolite has been used.

For travellers in a new country, traversing is the easiest and most generally adopted method of obtaining a rough outline map. Instead of chaining, the distances are obtained by pacing on foot or even by pacing on horseback. The average length of pace of the man or animal being measured, the paces are counted for distance, the change of direction being taken at the various turns by means of a pocket compass. A still rougher method is to judge the distance approximately by the time occupied in traversing it. The circumstances of the case will indicate the method to be adopted.

Chapter IV—LEVELLING

Construction of Level. Chain surveying is all surface work, differences of level being eliminated on the survey plans; when it is required to make a section to show variation of height,

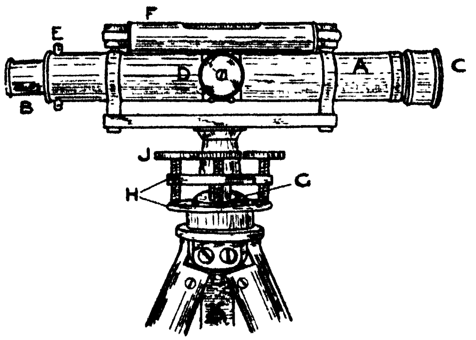


FIG. 47. BUILDER'S OR CONTRACTOR'S 10-INCH DUMPY LEVEL

some form of levelling instrument must be used. A *surveyor's level* consists essentially of an ordinary spirit level, with sundry attachments to facilitate its accurate use. The 10 in. *builder's or contractor's dumpy* is a cheap instrument, sufficient for all but the most accurate engineering work. A view of this is given in Fig. 47, where *A* is the body of the telescope, with the eyepiece at *B*, and object glass (called O.G.) at *C*. The object glass is moved in or out by the small wheel *D*, having on its spindle a pinion geared into a rack. Where the small screw-heads project at *E*, there is a diaphragm carrying cross wires for reading the height on a staff. *F* is a spirit level attached to the telescope by screws at each end, so that it may be adjusted to the optical axis of the telescope; *G* is a ball-and-socket joint, to permit a small movement of the upper plate in any direction; *H* are the parallel plates, and *J* the parallel plate screws; *K* is the tripod or legs. Having three points of support, the legs will stand firm, however irregular the ground may be.

Setting Up the Level. To set up the level before taking a reading, the parallel plates should be parallel, with the screws just up to their work. The instrument should be screwed on the tripod, the legs opened to be a couple of feet or so apart; then, the surveyor standing between two of the legs, with his left hand below the parallel plates, the telescope should be turned across the direction of the leg on the surveyor's right, and the leg moved to or from his body until the bubble of the spirit level is central; the telescope should then be turned in the direction of the leg, and the leg moved in or out towards the centre until the bubble is again central. The telescope should then be placed over a diagonal pair of screws, and the bubble finely adjusted by turning " thumbs in " to bring it to the right, or " thumbs out " to bring it to the left. Then, placing the telescope over the other pair of screws and adjusting as before, the bubble should remain central for any position of the telescope.

Fig. 48 shows the larger and more expensive *engineer's level*. The figures, " 10-inch " and " 14-inch," refer to the focal length of the telescope, and not to the length of the body. In the modern engineer's level the construction is similar to the others, but instead of four screws

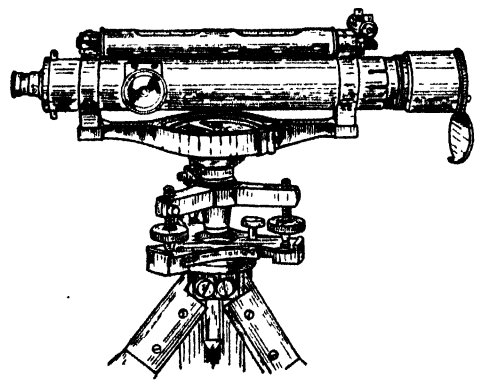


FIG. 48. ENGINEERS' 14-INCH DUMPY LEVEL

to the parallel plates there are only three, whence it is called a " tribach " instrument. In adjusting with these screws, the telescope is first put parallel with the paired screws and the bubble brought central, then over the tail screw and between the other two, and when the bubble is central the telescope is ready for use.

Level Staff. The level staff, upon which the heights are read, is made of many different patterns, the best is shown in Fig. 49 and is known as the " Sopwith " pattern, with three

lengths working telescopically. A portion of the staff is shown enlarged in Fig. 50. It is divided by red figures into feet, by black figures into tenths of a foot, and by black with equal white spaces into hundredths of a foot. This enlarged view is shown upside down as it appears upon looking through the telescope. To read where the cross wire in the telescope cuts the division of the staff, the eye passes from above

FIG. 49. SOPWITH TELESCOPIC LEVELLING STAFF

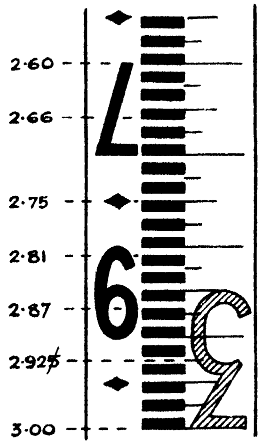


FIG. 50. ENLARGED VIEW OF PART OF STAFF WITH SAMPLE READINGS

downwards. No figure or division counts until it is passed; the black figures occupy exactly the tenth of a foot each; only the odd figures are shown, the 5 generally being a V to distinguish it from 3; the diamond shows the centre of where the even figures would come; the thin lines on the opposite side of the scale show respectively the $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and full distance of each tenth of a foot. The small figures and dotted lines, on the left of the staff, are simply placed there to give the present reader the opportunity of studying the divisions and method of reading. When the wire cuts the centre of a division, instead of reading the third decimal, it is omitted, and the next lower reading taken. About three chains is the usual distance at which the staff can be read with a small level, but with a larger one there is no difficulty in reading at a distance of ten chains in clear weather. By practice, a surveyor can read accurately when he is really too far off to see the small divisions, and can only judge by the proportion of the distance between the black figures. When the staff is too near to include a red figure in the field of view in the telescope, it can be read by looking outside the telescope along its axis.

Compass on Telescope. The compass seen below the telescope, in Fig. 48, is of little or no use; it is not easy to read in that position, and the level is an instrument for ascertaining

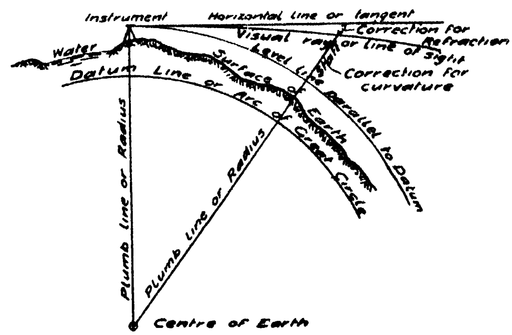


FIG. 51. RELATIONSHIP OF LEVEL, HORIZONTAL, AND VERTICAL LINES IN SIMPLE LEVELLING

heights and not directions. Even if directions were required, the compass is too small to give them with a sufficient degree of accuracy, and it is an unnecessary addition to the weight. The shutter to the object glass is useful for partly obscuring the object glass, when the light is too strong. The cap may be turned partly round to let the shutter hang with the right amount of opening; the cap may also be drawn forward to shield the object glass, when the sun is shining towards it. In the smaller telescopes, the surveyor does the same thing with his hand

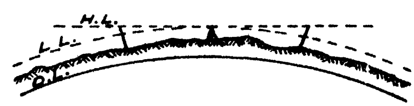


FIG. 52. CORRECTION AVOIDED WHEN STAFF POSITIONS EQUIDISTANT

held just clear of the object glass, but in a position to shelter it.

Footplate. A footplate, with a short chain attached to it, is sometimes used to rest the staff upon on soft ground, the plate being trodden down until firm. This is so that when reversed for a backsight the staff shall be upon the same level as it was for the foresight. If this is not done, the backsight may read one or two hundredths of a foot too much, and the plotting of the level section would not then be correct. The writer once had a pupil assisting him in

taking the levels alongside a stream; the ground was rather soft and for some of the backsights the pupil rested the staff on his foot. Upon examination of the notes the stream appeared to be running uphill, so that the work had to be done over again.

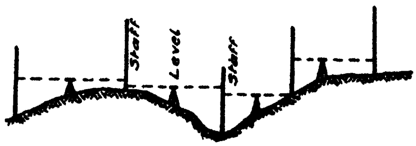


FIG. 53. COMPOUND LEVELLING

Principles of Levelling. Before we can go any farther with the use of the level, there are certain general principles that must be explained. Fig. 51 shows an exaggerated view of a portion of the earth's surface, with a level set up for taking a reading. A *plumb line* under the action of gravity hangs vertically, wherever it may be placed; that is, it points to the centre of the earth, so that a staff held vertically seems to slope when looked at on the illustration. The irregularity of the earth necessitates the use of a *datum line*, which may be assumed at any distance from the centre of the earth, and is the arc of a great circle. A large sheet of water, undisturbed by the wind, is part of a true sphere, and a section through its surface would give a curved line. *Ordnance datum* is the mean half-tide sea-level, and all ordnance heights are reckoned from it. In ordinary practice, a datum may be assumed at any level, commonly 10 ft. or 20 ft. below the first position of the staff. When the level is set up, the telescope is at right angles to a plumb line, and a straight line drawn through it would be horizontal and tangent to the mean surface of the earth at that point.

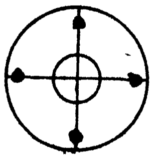


FIG. 54. DIAPHRAGM WITH CROSS WIRES

To read the true height above a datum line, we want a level line parallel to the datum. The relationship of these matters will be seen in the drawing. Now the actual line of sight through the telescope is neither level nor horizontal, but bent by refraction in passing through the air, thus necessitating a double correction, first for curvature, and secondly for refraction. The effect of curvature depends upon the distance of the staff, and makes the reading higher than it ought to be. The correction in feet is two-thirds of the distance in miles squared, and is always deducted. The effect of refraction is always to reduce that of curvature, and is taken approximately as equal to one-seventh of it. Suppose the reading on a staff at a distance of 20 chains is 8·42, and the height of the telescope 5·18, the difference of level between the two stations will be found as follows—

$$\left(\frac{20}{80}\right)^2 \times \frac{2}{3} = \cdot 042 \text{ correction for curvature.}$$

$$\frac{\cdot 042}{7} = \cdot 006 \text{ correction for refraction.}$$

$\cdot 042 - \cdot 006 = \cdot 036$ total correction.

$8\cdot 42 - 5\cdot 18 - \cdot 036 = 3\cdot 20$, say $3\cdot 20$ difference of level.

Simple and Compound Levelling. This is called "simple levelling," and, fortunately, it is very seldom required, but a surveyor must know all about it. By "compound levelling" all troubles are avoided. To explain the principle of compound levelling reference should be made to Fig. 52. where it will be seen that when the level is midway between two positions of the staff, if the ground were the same height in each case, the same reading would be obtained on each staff; likewise, if the ground differs in level, the true difference would be read, whether it be made by a horizontal line, or by a level line, or by the actual line of sight, which is neither. Fig. 53 shows how compound levelling is applied in practice, or, rather, how it would be applied if the principle were carried out exactly. It happens in nearly every case that the staff is nearer the level on one side than the other, but this does not introduce any error of consequence, as the correction required would be that due to the difference of distance only. Suppose on one side the staff is two chains off, and on the other side eight chains, the correction for curvature would be—

$$\left(\frac{8-2}{80}\right)^2 \times \frac{2}{3} = \cdot 00375 \text{ ft., which is quite}$$

negligible.

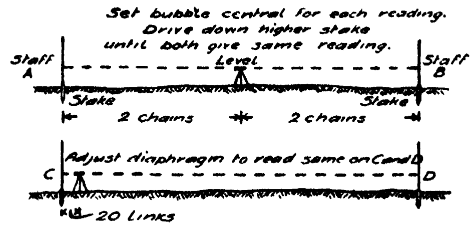


FIG. 55. ADJUSTMENT OF LEVEL FOR COLLIMATION

Adjustments of Level. There are two adjustments that a surveyor has to make to the level from time to time. If for any purpose the eyepiece is taken out too rapidly, the rush of air in the tube may break the wire, which is only of spider web, and it will be necessary to renew it. The four diaphragm screws being removed

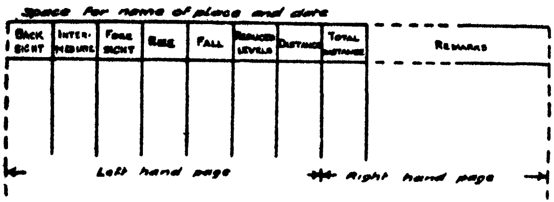
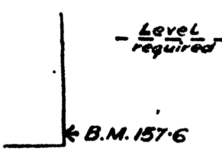


FIG. 56. RULING FOR LEVEL BOOK

the diaphragm, Fig. 54, is taken out and held between the thumb and first finger of the left hand. A drop of strong gum is dropped on each side where the wire is to come, and the diaphragm is held behind a single thread of a spider web; then, the thread being held down by the thumb on one side, the hand is moved to tighten the thread, which is then held down on the other side and the ends cut with scissors. Fine marks will be found cut in the face of the diaphragm to assist in placing the thread correctly. If an



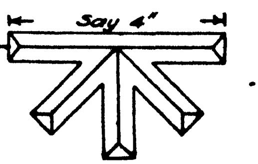


FIG. 57. BENCH MARK ON ORDNANCE MAPS

FIG. 58. ORDNANCE BENCH MARK CUT ON WALL

attempt is made to break the thread, it will be found that it will fray out into still smaller threads, and probably shift on the diaphragm.

The *adjustment for parallax* consists of focusing the eyepiece by pulling it gently in or out always turning it to the right at the same time, until the wire can be clearly seen. Sometimes it is necessary partly to shade the object glass with the hand while this is being done. When this adjustment is properly made a slight movement of the eye causes no apparent displacement of the wire when reading the staff.

Collimation. The other adjustment is for collimation, required when a new wire, or web, has been put in. Set up the level midway between two stakes, driven in the ground about four chains apart, as in Fig. 55. With the bubble central for each reading, whether it reverses properly or not, sight the staff at A and B, and drive down the stake that gives the lesser reading until they are both equal. Then shift the instrument to about 20 links from one of the stakes, and take the reading from both. As they are both at the same level they should give the same reading; but if they do not, by slackening one of the diaphragm

Levels at Westend — *10th Aug. 1924*

Back sight	Inter-mediate	Fore sight	Rise	Fall	Reduced levels	Distance	Total distance	Remarks
7·07					9·50		0·00	B.M on lower hinge of gate of Westend Cottage
8·02		3·43	3·64		13·14	1·42	1·42	
5·84		2·19	5·83		18·97	1·96	3·38	
7·02		1·12	4·72		23·69	2·40	5·78	
5·62		1·51	5·51		29·20	2·72	8·50	
3·65		1·28	4·39		33·59	2·60	11·10	
	1·51		2·34		35·93	·94	12·04	
		0·64	·67		36·60			O.B.M on pier at White Lion Inn.
37·22		10·12	27·10		27·10	12·04		
10·12								
27·10								

Plot to scales of Hor. 1ch. = 1in., Vert: 10ft. = 1in.

FIG. 59. LEVEL NOTES OF SECTION

screws on the vertical line, and tightening the other, it will soon be seen which way the diaphragm should be moved to make both readings alike.

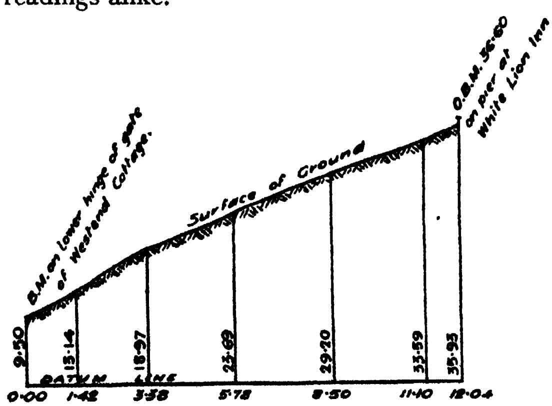


FIG. 60. PLOTTING OF SECTION

FIELD NOTES

Flying Levels and Section Levels. If the object in view in levelling over a piece of ground is only to obtain the difference in level between two or more given points, no distances need be measured; but if a section of the route is required, the distance from station to station of the staff must be measured. It does not

matter where the level is set up so long as the telescope can read the staff at two adjacent stations; naturally, it would be set up about midway, but not necessarily in the direct line. The positions for the staff should be selected to give the various changes of gradient, very similar to the way the positions are selected for offsets in chain surveys.

Level Book. The level book is ruled and headed as shown in Fig. 56. The first reading, after setting up the level, will always be a backsight on a line by itself. On the same line, under the head of "reduced levels," or "height above base," will be entered the level of the point where the staff rests, either above Ordnance datum or above an assumed datum, such that, in plotting, the surface of the ground will be everywhere above the datum line.

The Ordnance datum may be obtained by referring to an Ordnance map of the district, and noting the figures placed alongside the nearest bench mark, shown as in Fig. 57, which will generally be found cut on a wall as in Fig. 58. To work from this mark, a knife blade is held in the horizontal groove, and the staff rested upon it.

Keeping a Level Book. The "intermediate" column is for readings taken from the staff at any points intermediate between the two stations, for the sake of getting the exact contour. An intermediate will always be on a line by itself, because it has a different reduced level from either backsight or foresight. The last reading before shifting the instrument forward will always be a foresight, and put on the next line; but the next reading (a backsight) will be taken with the staff turned round, yet remaining at the same point, and therefore the entry will be on the same line as the foresight, because it is really the same level read from a different position. To each of these readings there should be an entry in the "distance" column, giving the measurement from point to point. These are all called "field columns," because they must be entered up at the time; the others are called "office columns," because they can be entered up later. The difference between the backsight and the next reading, whether intermediate or foresight, will be entered on the same line as the latter, under the head "rise" or "fall," as the case may be; the second reading is greater when the ground falls and less when it rises. Then the rise is added, or the fall deducted, from the last reduced level and put upon the same line. The distance is added to the total distance, and also put upon the same line.

Rose Hill, Main and Cross-Section — *17th Sept. 1924*

Back Sight	Intermediate	Fore Sight	Rise	Fall	Reduced Levels	Distance	Total Distance	Remarks
2 90					85·00		0·00	
	6·80			3·90	81·10	1·54	1·54	
1·42		12·10		5·30	75·80	1·50	3·04	
	3·95			2·53	73·27	1·54	4·58	At junc of cross-roads
	2·70		1·25		74·52			2·00 up road on left
	9·53			6·83	67 69			2 00 " " " right
0·87		7·51	2·02		69·71	1·35	5·93	
0·41		13 06		12·19	57·52	2·00	7·93	
0·53		11·91		11·50	46 02	1·50	9·43	
2·96		11·62		11·09	34 93	1·44	10 87	
		9·14		6·18	28 75	2·10	12·97	
9·09		65·34	3·27	59 52	56·25	12 97		
		9·09		3·27				
		56·25		56·25				

Plot to scales of Hor, 1ch = 1in, Vert., 20Ft. = 1in.

FIG. 61. LEVEL NOTES OF MAIN AND CROSS-SECTION

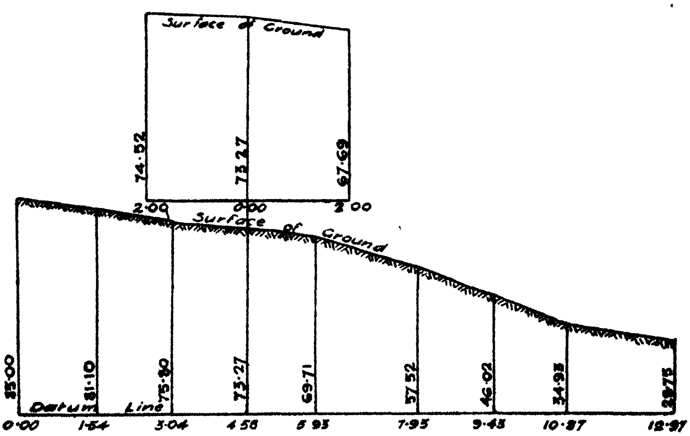


FIG. 62. PLOTTING OF MAIN AND CROSS-SECTION

The column for remarks is for any entry that may be required, such as the position of the Ordnance bench mark, or any other bench mark that may be used. The description should be

such that a stranger may recognize from it the exact position. Every page should begin with a backsight and end with a foresight. These two columns should be added up at the bottom of the page, and the total of the lesser put under the greater, so that the difference may be shown. The rise and fall columns should then be added up, the total of the lesser put under the greater, and the difference should equal the difference of the backsights and foresights. The difference between the first and last reduced levels should equal the difference between the two pairs of columns, just described. Lastly, the total of the distance column should equal the last reading of the total distance column. Each page of the book should be treated in this way, carrying forward not the final balance but the total of each column, and this check upon the work should be carried right through the survey.

Page 1. Hereford & Marden. Final levels 29/5/99.

Back Sight	Intermediate	Fore Sight	Rise	Fall	Reduced Levels	Distance	Total Distance	Remarks
9·96					100·00	B M.[1]		*Taken in the centre on string course of bridge over Canal.*
	10·85			0·89	99·11			*Centre of road from Hereford to Mordiford.*
	4·81		6·04		105·15		0·67	*Bank of field*
								Road X 0·00 & 0 65.
3·49		6·38		1·57	103·58		1·50	*Hedge X at 4·54*
2·57		7·25		3 76	99 82		4·55	
4·46		10·64		8 07	91·75		7 00	
4·63		6·54		2·08	89·67		11 00	*Mill pond X 12·30 & 16·00*
6·33		3·12	1·51		91·18		12·10	*On bank of mill pond*
	7·33			1·00	90 18			*Surface of water in pond*
10·18		2·46	4·87		95 05		16·00	
11·94		1·08	9·10		104·15		17·50	
4·48		3·53	8·41		112·56		21·00	*Hedge X 25·33*
6 08		4·75		0 27	112·29		25·00	*Hedge X 26·72*
3·28		6·43		0·35	111·94		28·00	
6·75		9·03		5·75	106·19		30 00	*Road X 30 57 & 32·40*
11·89		3·14	3·61		109·80		31·65	*Centre of road from Hereford to Worcester*
	5·84		6·05		115·85	B M.[2]		*On lower hinge of gate opposite Crown Inn.*
		1·83	4 01		119·86		33·50	*Hedge X.*
86·04		66·18	43·60	23·74				
66·18			23·74		100·00			
19·86			19·86		19 86			

FIG. 63. LEVEL BOOK FOR PART OF RAILWAY SURVEY

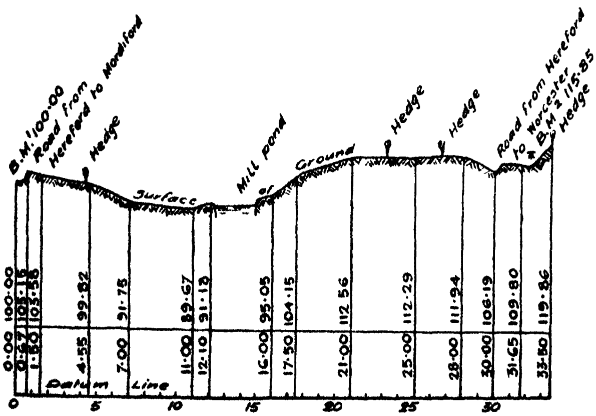


FIG. 64. PLOTTED SECTION FROM FIG. 63

Entries for Sections. Fig. 59 shows the entries in the level book for a small section, and Fig. 60 shows the plotting of the section. An enlarged scale is always used for the vertical measurements, in order to render the changes of level more conspicuous. The distances and heights are marked on the section as shown. Common scales are 1 in. to one chain horizontal, and 10 ft. to 1 in. vertical. Fig. 61 gives the entries for another series of levels, and shows also how a cross-section is noted where another road, or section, crosses the main line. Fig. 62 shows the plotting of these entries, and how the cross-section is indicated at the point where it occurs, being, as it were, pivoted above its true position. The cross-section may also be detached from the main section and shown separately, which is convenient if there are many of them.

If the line of section is taken across country, other notes will appear in the remarks column, and will be shown upon the section as "hedge crosses," name of road, or lane crossed, etc. This will be best shown by taking a page of the level book of an actual railway survey, as in Fig. 63, with the plotted section, Fig. 64. These should be carefully studied, as much is to be learnt even from such a short example as this; the section should be plotted for practice to a horizontal scale of, say, four chains to 1 in., and a vertical scale of 40 ft. to 1 in.

Chapter V—ANGULAR MEASUREMENTS

CHAIN surveying and levelling form the simplest part of a surveyor's work, and the previous notes give a thorough practical insight into the method of carrying them out. For large surveys it is necessary to be able to use the *theodolite*, which is a very precise instrument for measuring angles, and correspondingly expensive. The old definition of an angle as "the opening made by the inclination of two straight lines, which meet together in a point," is hardly comprehensive enough. We want to add to this definition the words "or would do if produced," because the angle is equally definite if the lines do not actually meet, although in that case it is rather more difficult to measure the angle.

The best idea of an angle can be obtained by considering it as the opening between two radii of a circle, and then it will be understood that an angle may be anything from zero to 360°. An angle of 180° is the space above or below a straight line with regard to any point in the line. An angle of 270° is the space outside the lines which form a right angle. An angle of 450° would be a revolution and a quarter. Such an angle is used in practice to describe the arc through which a crane can be made to swing. Angles are measured in *degrees*, *minutes*, and *seconds*, the minutes being sixtieths of a degree, and the seconds being sixtieths of a minute. To enable such fine divisions to be measured, it is necessary to use a vernier.

Vernier. This is a small sliding scale placed against a larger one, and may be either straight, as in a standard barometer, or curved and worked from a centre, as in a box sextant and theodolite.

Fig. 65 shows a simple straight scale where, if the main scale be inches and tenths, the vernier enables hundredths of an inch to be read. The vernier has a length of nine divisions of the primary scale, divided into ten parts, so that each is one-tenth of a tenth shorter than the numbered divisions on the primary scale. The reading is from the broad arrow forwards to the left in the direction the scale is marked. First, the position of the arrow must be noted; it reads 2·3 and a bit over; the value of this bit is found by looking along the two scales to where the lines coincide. This is seen to be at 7 on the vernier, so that the full reading is 2·37.

The box sextant vernier, working on the centre, appears like Fig. 66. Here, the larger divisions on the outer curve give degrees, each of which is divided to show 30 minutes.

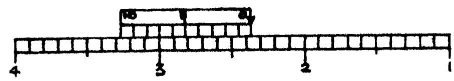


FIG. 65. SIMPLE VERNIER SCALE

Then 29 of these divisions are subdivided into 30 parts of the vernier to give single minutes. The scale on the theodolite is on the same principle, but the single degrees on the primary scale are subdivided into three parts of 20 minutes each, and the vernier has 20 divisions for minutes, each divided into two,

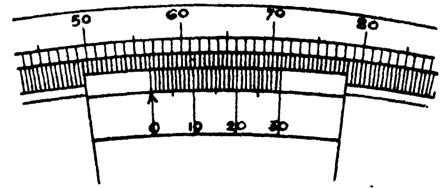


FIG. 66. PRIMARY SCALE WITH VERNIER AS ON SEXTANT

to read to 30 seconds; 39 of the small divisions on the primary scale make 40 divisions on the vernier. Different makes of instruments may be found with different subdivisions, but there will be no difficulty in reading them, as they are all on the same principle.

Box Sextant. The box sextant is the simplest instrument for visual measurement of angles, but being usually without a telescope and held in the hand, it can be used to sight only short distances. It is very much the same as an optical square, with one of the mirrors movable. This movable mirror is attached to an arm carrying a vernier, which travels over a divided arc to show the range of movement. Fig. 67 shows the plan, which with the description attached is self-explanatory. Fig. 68 is the general view. When a telescope is attached it is placed as shown by the dotted lines. The length of the arc on a box sextant extends from

5° below zero to about 145° above zero, although above 120° the mirror is so nearly edgeways that it is difficult to read accurately. The angle at

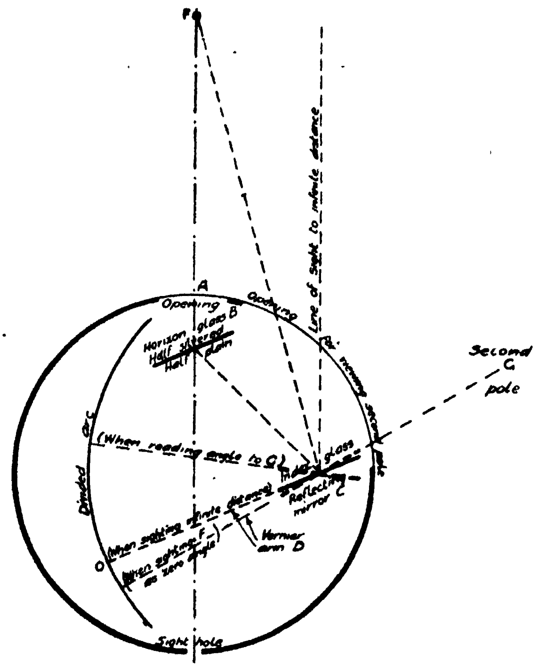


FIG. 67. DIAGRAM SHOWING PRINCIPLE OF BOX SEXTANT

any given station is read to station poles, fixed at the required points, but when the angle exceeds 90°, it is better to insert an intermediate

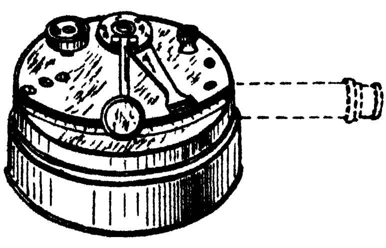


FIG. 68. SKETCH OF BOX SEXTANT

pole between the other two and take the sum of the two angles *A* and *B*, as in Fig. 69. It will be seen from the diagram, Fig. 67, that the zero on the scale is only attained normally by sighting a pole in a straight line at an infinite distance, while sighting to a near pole the vernier will show an angle below zero. In practice the mirrors are so adjusted that the vernier reads zero when a pole is sighted in the direct line of sight at a moderate distance, say two chains; and to ensure the greatest accuracy when sighting the angle between two poles, the sextant should be turned upside down if necessary, so that the farther pole should be the one in the direct line of sight; it does not matter then how near the other may be.

The box sextant sometimes has a slide with a dark glass at the sight hole for the purpose of adjusting the mirrors by sighting to the sun, which should show as a perfect circle when the instrument is set to zero.

The plain circular portion at the bottom of Fig. 68 unscrews and forms a cover to the box

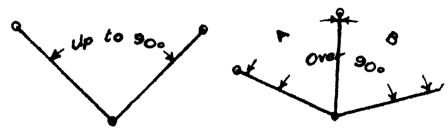


FIG. 69. READING ANGLES WITH BOX SEXTANT

sextant, so as to protect it from injury when not in use; it also forms a convenient part to hold when in use as shown. Instead of being screwed it is sometimes attached by a simple bayonet joint, which is rather a better arrangement. The smaller round glass with the arc, shown in the front of Fig. 68, is a magnifier to enable the vernier to be read more easily. The milled head on top is attached by a rack and pinion to the vernier drum for adjusting the reflecting mirror when observing an angle. The sextant is held in the left hand, leaving the right hand free to turn the milled head.

The Theodolite. A transit theodolite, as in Fig. 70, is generally used by engineers. The full vertical scale makes it a transit instrument, enabling it to be used for tunnelling or astronomical observations. The nominal size is due to the horizontal circle, which may be 4 in., 5 in., or 6 in. diameter. The smaller sizes have two verniers opposite each other, and the larger sizes sometimes three.

The eyepiece *A* may have a branch, as shown, for reading by a reflector, when the telescope is vertical. The diaphragm at *B* has three wires at equal angles crossing in the centre, the optical axis passing through their intersection. The object glass *C* is smaller than in the level, but with good definition. The vertical circle is attached to the telescope, and moves with it. The vernier arms *DD* are attached to a vertical arm *E*, making together a tee piece, which is

adjustable between two screws FF. The clamp G holds the verniers in any position, allowing fine adjustment by the tangent screw H. The spirit-level J is attached to the vernier arms in the illustration, but is sometimes placed on top of the telescope. A circular compass is shown between the A frames, but this is sometimes advantageously replaced by a long, narrow

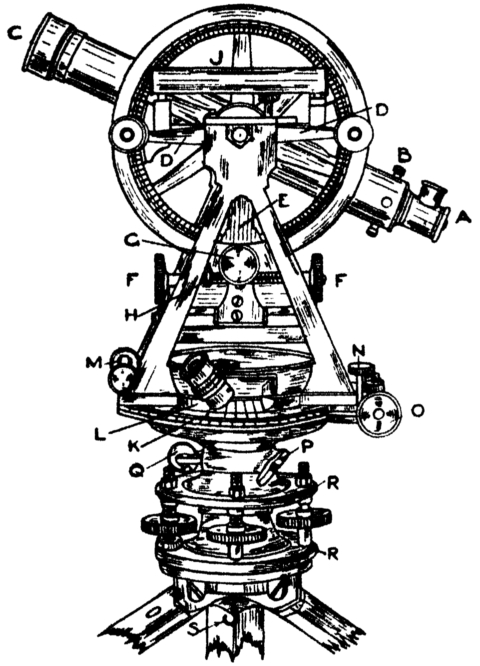


FIG. 70. GENERAL VIEW OF THEODOLITE

box, allowing a movement of the needle about 5° each side of zero. The horizontal circle K has a circular plate L above it, carrying the A frames and the verniers. A microscope is fitted to each of the verniers. A spirit level M is shown at the side for levelling the plates, and a second spirit level at right angles to this is often fixed in the A frame. N is a clamp for holding the plates together when the position is roughly fixed, and the tangent screw O then enables the fine adjustment to be made. P is the lower clamp for fixing the whole instrument to the vertical spindle, and Q the fine adjustment for it. The parallel plates RR, with their screws, are the same as in the level, and adjusted in the same way. There may be three or four screws, according to the date of the instrument. The tripod has the same general construction as for a level, but the hook S, under the centre of the brass head, is a very important adjunct, as a plummet hung to this enables the theodolite to be centred exactly over the required station.

SETTING UP. To set up the theodolite, fix it on the tripod, place the legs as for the level, and stand between two of them. See that the parallel plates are about parallel, and the screws just up to their work without any clearance at the points. Hang on the plummet, and shift the instrument bodily until the plummet is nearly over the right spot. Then adjust the leg on the right by the two lower spirit levels. Look at the position of the plummet; note how far and in what direction it requires to move to bring it over the right spot. Then shift the two legs that are not being used for adjustment in the direction and to the amount indicated by the plummet, but do not look at the plummet while doing this, as it will only mislead.

After shifting the two legs as described, readjust the leg on the right to bring the bubbles central; then look at the plummet to find if it wants still finer adjustment; if so, go through the operation again until correct. Now see that all the clamps are loose, and set the instrument true by the parallel plate screws; set the horizontal vernier on the left of the eyepiece to zero; clamp and verify by the microscope and fine adjustment. Set the vertical circle to zero on the vernier, and clamp it. By the two screws F adjust the upper spirit-level, so that the bubble is in the centre of its run when the telescope is at zero. Sight through the telescope to see that the wires are clear, and the instrument is then ready for reading angles. Be careful not to try to shift the telescope while clamps are fixed. Some surveyors, who have much practice, take their first reading of a horizontal angle

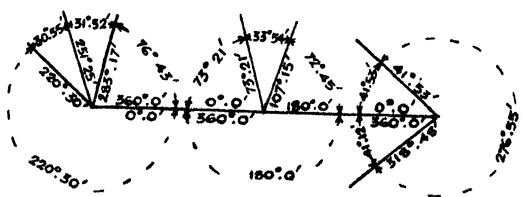


FIG. 71. RECORDING ANGLES WITH THEODOLITE

wherever the vernier may happen to be, and then take the difference of reading when the telescope is turned in the direction to give the required angle. By not setting to zero first, the wear of the clamp at that particular part is avoided, to the ultimate advantage of the theodolite.

READING THE ANGLE. The reading should always be taken from both verniers, when the difference should be 180°, but it is often a minute or more out, owing to inaccuracy in the divisions. For important work it is necessary to repeat the angle, which may be done in the following way. After reading the required angle, loosen the lower clamp and then turn the telescope back to the first station; clamp and get the fine adjustment; then loosen upper clamp and turn the telescope on to the second station, so that twice the angle is included. This may be done a third time, and the readings entered thus—

LEFT-HAND VERNIER		RIGHT-HAND VERNIER	
From	0° ·0′	From	179° ·59′
1st reading .	84° ·29′	1st reading .	264° ·26′
2nd ,, .	168° ·56′	2nd ,, .	348° ·54′
3rd ,, .	253° ·22′	passing .	360° ·00′
6	6)506° ·47′	3rd reading .	73° ·21′
	84° ·27′ ·50″	6	1226° ·40′
	84° 27′ ·50″	(4 times 180)	720° ·00′
	84° ·26′ ·40″		6)506° ·40′
	2)168° ·54′ ·30″		84° ·26′ ·40″
	84° ·27′ ·15″		

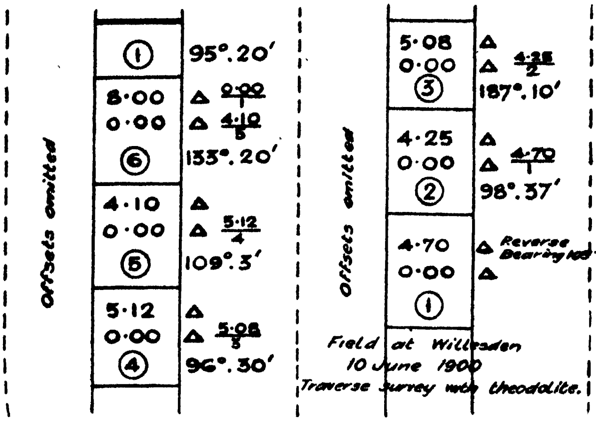


FIG. 72. FIELD NOTES FOR TRAVERSE SURVEY WITH THEODOLITE

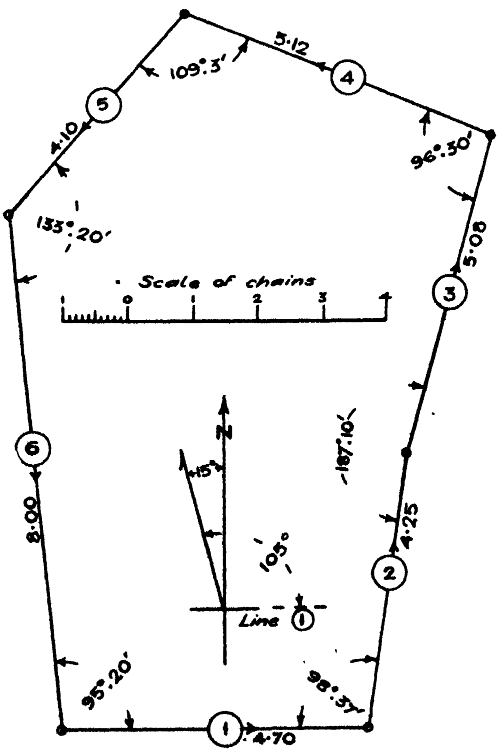


FIG. 73. PLOTTING OF FIG. 72

There is a rather shorter method, but the above will probably be better understood.

Fig. 71 shows how the theodolite may be used to check the lines of a survey. The angles should be read from zero right round to 360, or zero again, when sighting on the first station; this provides against the accidental slipping of either of the clamps, and is a valuable safeguard.

METHOD OF USE. There are two methods of using the theodolite in land surveying: the first is by traversing round the boundaries, chaining the lines, and observing the angles; and the other is by surveying from two stations. The first method has two modifications: (*a*) surveying by the back angle, i.e. taking the angle from the line previously measured to the new line; and (*b*) taking all the angles from the magnetic meridian. Some books say the telescope should always be turned clockwise, because the divisions are marked that way; but whichever way it is turned the result will be the same, as the vernier will be set at precisely the same place in either direction.

Fig. 72 is the field book for a survey made by the back angle with the offsets omitted, and Fig. 73 the plotting of the same. Chain stations are marked as before by a small circle with a dot in it; "trig" stations, where the theodolite is set up, are marked by a small triangle. All the internal angles of a closed traverse should total up to four less than twice as many right angles as the figure has sides.

In this case—

98° ·37′	Sides . .	6
187 ·10	Multiply by .	2
96 ·30		—
109 ·03		12
133 ·20	Right angles .	12 − 4 = 8
95 ·20		
720° ·00′	$8 \times 90 = 720$ degrees.	

The general errors in a survey are known as "compensating" and "cumulative" errors; the former when the error is due to want of care, which may result in an error of "more or less," and the latter when the error is due to such a cause as a stretched chain.

As the errors in reading theodolite angles are independent of the magnitude of the angle, it is usual to correct the summation error by distributing it equally over the whole of the angles, but a useful check in a closed traverse may often be obtained by sighting to distant stations to triangulate the whole.

In theodolite surveying by taking the angles from the meridian, it is necessary to have the long compass needle previously described; the circular compass box, under the telescope, is almost useless from its small size and the difficulty of reading it accurately.

A field may also be surveyed from two stations at the ends of a carefully selected and measured base line. Fig. 74 shows the same field of six acres surveyed in this manner, and Fig. 75 the corresponding field book.

Great Triangulation. For surveying on a large scale "great triangulation" is used. It is commenced by a base line very carefully set out on level ground, and measured with the greatest possible degree of accuracy. Observations are then made to prominent points in a system of triangulation reading to as many stations as can be seen from where the theodolite is set up. In the trigonometrical survey of Great Britain, a base line was laid out on Salisbury Plain nearly seven miles long, and from its extremities progressive observations were extended to 250 trigonometrical stations over the whole kingdom. All the distances from point to point were calculated, and a line of verification was laid down in Ireland nearly eight miles long, which differed from its calculated length by a little over 5 in. Every pair of stations in such a survey becomes a base line for new positions, but there are certain difficulties to be overcome in practical work that we need not consider here. Very little progress can be made with the

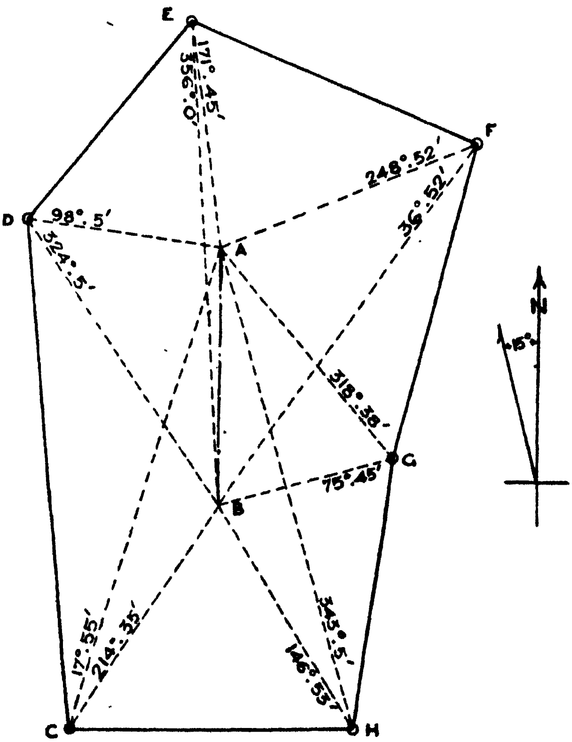


FIG. 74. THEODOLITE SURVEY FROM TWO STATIONS

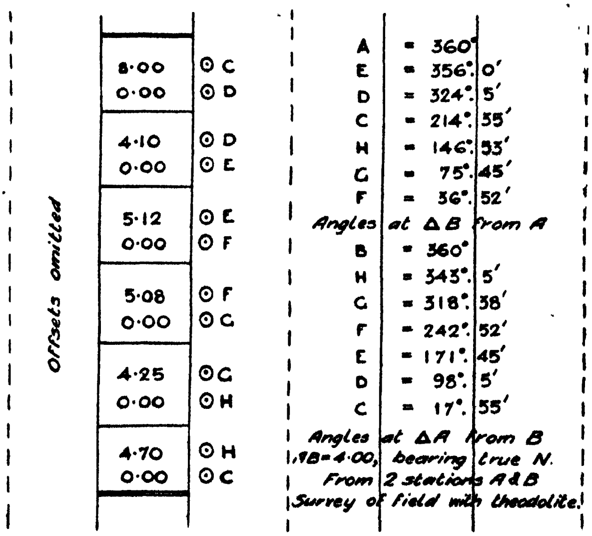


FIG. 75. FIELD NOTES FOR FIG. 74

theodolite without a knowledge of trigonometry. The best book for the purpose is *Practical Trigonometry for Engineers, Architects, and Surveyors* (Pitman & Sons).

Practical Observations for Height. Judging by the examples given in the textbooks, the observations necessary to enable the height of any point to be ascertained are very simple; in practice it is far otherwise. A fairly easy case is shown in Fig. 76, where the height of the finial of a church above the pavement was required. The theodolite was set up at *A* and *B*, the height to axis of telescope measured, and the angles to top of finial taken. From *B* to *C* the difference of level was taken by compound levelling, setting the vertical circle of the theodolite to zero and using it as a level. A careful study of the diagram will show what observations are necessary to overcome the difference in level of the ground, and the height of the instrument. The calculations are then directed to the reduction of the various lines to a plane triangle, and thus bring the problem into the form required under the head of solution of triangles in the mathematical books. The calculations are as follows—

$5{\cdot}08 - 4{\cdot}96 = 0{\cdot}12$

True base $= \sqrt{38^2 - 0{\cdot}12^2} = 37{\cdot}9999$

Difference of axes $= 4{\cdot}99 - 4{\cdot}96 = 0{\cdot}03$

Reduction of base $= 0{\cdot}03 \cot 36^\circ\, 39'$

$= 0{\cdot}03 \times 1{\cdot}34405$

$= {\cdot}0403215$

Virtual base $= 37{\cdot}9999 - {\cdot}04032$

$= 37{\cdot}9596$

Log d log $a + L \sin 32{\cdot}3 + L \sin 36{\cdot}39 - L \sin (36{\cdot}39 - 32{\cdot}3) - 10$

$= 1{\cdot}5793217 + 9{\cdot}7248156 + 9{\cdot}7759199 - 8{\cdot}9041685 - 10$

$= 2{\cdot}1759 \quad \therefore d = 149{\cdot}93$

Required height $= 149{\cdot}93 + 5{\cdot}93 - (4{\cdot}99 - 4{\cdot}96)$

$= 155{\cdot}83$

Reduction to Sea-level. In large trigonometrical surveys it is necessary to reduce the length of the base line to its equivalent length at mean sea-level.

Let L = measured length of base in feet;

l = equivalent length at sea-level in feet;

h = height of base line in feet above sea-level;

R = radius of earth to mean sea-level,

$= 21{,}000{,}000$ ft.

Then, $R + h : R :: L : l$

$$\therefore l = \frac{RL}{R+h}$$

$$\text{Difference } L - l = L - \frac{RL}{R+h}$$

$$= \frac{LR + Lh - RL}{R+h} = \frac{Lh}{R+h}$$

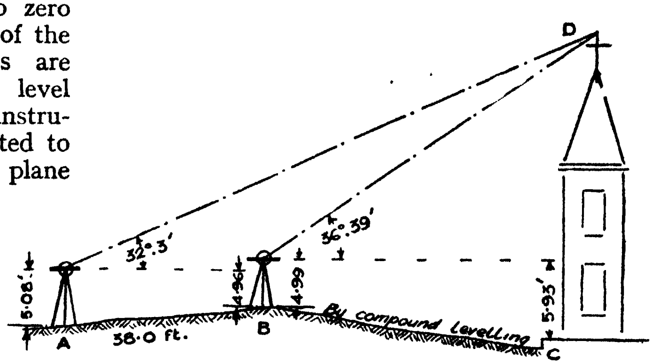


FIG. 76. OBSERVATIONS FOR HEIGHT OF STEEPLE

Town Surveying. Town surveying is much more difficult than surveying in the open country for many reasons. Double chain lines are often used, one down each footpath. The angles of all junctions of lines are taken by the theodolite, as are also triangulated offsets from the chain lines to the principal offsets, so as to avoid any error due to want of perpendicularity in the measurement.

In making a survey of a plot of land covered with buildings to be pulled down, the greatest care is necessary. The measurements must be reliable to $\frac{1}{8}$ in., so that steelwork may be ordered from the plans and fit together when received. A standard 100 ft. steel tape is required; it should be checked against the Trafalgar Square standard and the temperature taken, so that allowance may be made for any error or difference of temperature when it is used. French nails or galvanized clout nails, $1\frac{1}{2}$ in. long, should be driven into the footpath, or roadway, to mark the exact stations selected for the survey, and left in permanently. A good

theodolite should be used to take all angles, and calculation made to see that the angles give the same result as the measured lengths. An island site is less trouble than one having only three sides available; in the latter case the diagonals should be calculated from the base line and side lines, and also the back line, the back line being checked as far as possible by breaking through any intermediate walls for actual measurement. A site, roughly 300 ft. by 200 ft., drawn to a scale of $\frac{1}{8}$ in. to 1 ft., would have the selected stations carefully plotted from a 3 ft. 6 in. brass scale, using a strong magnifying glass, and remembering that $\frac{1}{100}$ in. on the plan means 1 in. on the site. Then, when the complete boundary of the site is plotted, the length of each part may be inserted; and the measured length between the stations, being found to agree with the calculations, may be inserted on the plan. The paper or linen on which the survey is plotted will vary in size with the weather, making it essential to work from the written dimensions for all main features, and only scaling for minor details. The survey has to be made before the site is cleared, so that the designs may be proceeded with while this is taking place. The work of making a town survey of this class is often much more difficult than would appear from the above description, even when advantage is taken of early daylight on a Sunday when the traffic is a minimum.

PROBLEMS

Heights and Distances. There are two ordinary cases that arise in the measurement of heights

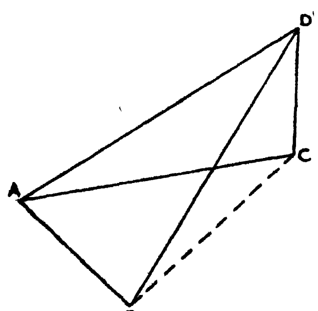


FIG. 77. OBSERVATIONS FOR DISTANT HEIGHT

and distances. Fig. 77 shows a perspective view of the lines, where AB is a horizontal base, and D a point whose height is required above C on the same level as AB. Then $\log DC = \log AB + L \sin ABD + L \sin DAC - L \sin (DAB + ABD) - 10$. These angles would be taken by a box sextant in order to obtain them in the plane DAB. If a theodolite be used, the angles observed would be BAC, ABC, DAC; then $\log DC = \log AB + L \sin ABC + L \tan DAC - L \sin (BAC + ABC) - 10$.

The other ordinary case is to find the distance between two inaccessible points, as in Fig. 78,

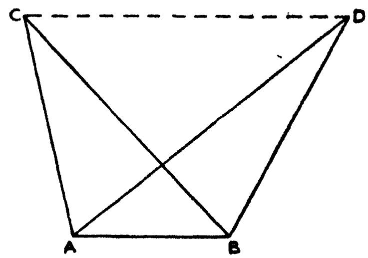


FIG. 78. OBSERVATIONS FOR DISTANCE BETWEEN INACCESSIBLE POINTS

where AB is a level base line, and C and D the two inaccessible points. Then $\log CB = \log AB + L \sin CAB - L \sin BCA$, and $\log DB = \log AB + L \sin DAB - L \sin ADB$, whence CB and DB are known. Then $L \tan \phi = \log 2 + \frac{1}{2} \log CB + \frac{1}{2} \log DB - \log (CB - DB) + L \sin \frac{CBD}{2}$, and $\log CD = \log (CB - DB) + L \sec \phi - 10$. It must be noted that ϕ is an imaginary angle, found from the equation given for $L \tan \phi$, and that the secant of the same angle is required in the final equation.

Examination Work. Sometimes an examination question may give trouble from the way it is stated, as in the following case: Show how to find the points C and D from the following angles taken with a theodolite to the ends of base line AB, which is 6,230 yd. long.

$$\angle ACB = 85^\circ 46' \quad \angle BCD = 23^\circ 56'$$
$$\angle ADC = 31^\circ 48' \quad \angle ADB = 68^\circ 2'$$

A rough sketch should be made so that the given data may be clearly understood, then the working will be as follows—

Assume CD to be x yards long,

then $CA = x \times \dfrac{\sin CDA}{\sin CAD}$ and $CB = x \times \dfrac{\sin CDB}{\sin CBD}$

whence

$$AB = \sqrt{(CA)^2 + (CB)^2 - 2\,\overline{CA}\,\overline{CB} \cos ACB}$$

but $AB = 6{,}230$ yd.

$$\therefore \sqrt{(CA)^2 + (CB)^2 - 2\,\overline{CA}\,\overline{CB} \cos ACB} = 6230$$

$$\overline{CA} = x \times \frac{\sin 31^\circ 48'}{\sin 86^\circ 22'} = x \times \frac{0{\cdot}527}{0{\cdot}998} = {\cdot}538x$$

$$\overline{CB} = x \times \frac{\sin 36^\circ 14'}{\sin 119^\circ 50'} = x \times \frac{0{\cdot}5911}{0{\cdot}8675} = {\cdot}6814x$$

$$\cos ACB = \cos 85^\circ 46' = {\cdot}0738$$

$$\therefore 6.30 =$$

$$\sqrt{({\cdot}538x)^2 + ({\cdot}6814)x^2 - 2 \times {\cdot}538x \times {\cdot}6814x \times {\cdot}0738}$$

$$= \sqrt{{\cdot}2894x^2 + {\cdot}4643x^2 - {\cdot}0541x^2}$$

$$\text{or } 6230^2 = {\cdot}6996x^2$$

$$\therefore x = \sqrt{\frac{6230 \times 6230}{{\cdot}6996}} = \sqrt{55{,}478{,}702{\cdot}1154}$$

$$= \underline{7{,}448{\cdot}40 \text{ yd.}}$$

The outlines may now be plotted as in Fig. 79, and the length CD scaled off as an approximate check upon the calculations.

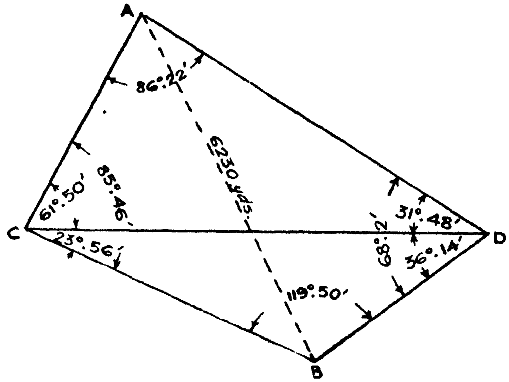


FIG. 79. PLOTTING OF EXAMINATION QUESTION AFTER CALCULATION

Specifications and Quantities

By Wilfrid L. Evershed, F.S.I.
Chartered Quantity Surveyor ; Author of "Quantity Surveying for Builders" and "Specifications for Building Works"

Chapter I—SPECIFICATIONS

Introduction. The art of writing a specification depends upon a knowledge of the wishes of the architect, and also the ability to write in such a way that the person reading same can understand what is required. It will therefore be realized that there is a difference between specification writing and writing the description attached to items in a bill of quantities. The latter is simply a description of the work and has certain dimensions attached to it, and will always be read by someone who understands what is required ; while in a specification the reading should convey instructions to workmen and others who have not always the advantage of the education or knowledge that the man has who will read the bill of quantities.

QUANTITIES. The preparation of quantities is a subject which requires infinite care and patience, and a mind fitted to deal with a mass of detail. It must be remembered that the architect's plans are being dissected, and where one or two lines on the plans may represent a door or window, this has to be split, from the surveyor's point of view, into a deduction from walling, plastering, facing, etc., and also into arches, lintels, sills, reveals, door or window frames, doors or sashes, various fastenings, painting, glazing, etc. It will thus be realized how necessary is the knowledge of construction before one attempts to " take off " this work.

The general course followed by students when studying the actual work in a surveyor's office, is first to square dimensions, or in other words, to work out into superficial and other measurements, the figures which have been placed on dimension paper by the " taker off." Following this, he will advance by slow stages to that of " worker up," which process is that of " abstracting " and " billing," and it may be some time before he is allowed to do any " taking off," and then will only start on the much easier portions of a building, such as plastering.

In this work, however, the subjects are given in the actual order in which the work is carried out, and therefore the " working up " process will not be described until towards the end.

ESTIMATES. There are various methods employed to obtain estimates for both building and civil engineering works ; but there is no real difference between the preparation of quantities for houses and public buildings, harbours, roads, etc. ; the student who can " take off " a public building can just as easily apply his knowledge to harbours, roads, and sewers.

The various methods are—

Cubing the building.
Taking off rough quantities.
The use of schedules.
The preparation of an accurate bill of quantities.

Cubing. This method is only employed to obtain an approximate idea of the cost, and is often used by a builder or contractor as a check upon his priced bill of quantities. Before he can check in this way he must have some idea of the cost per foot cube for buildings of a similar description to that under review.

Rough Quantities. These consist of superficial dimensions of walls, floors, roofs, and similar items, approximately accurate as far as dimensions are concerned, but including in their description the brickwork facing, plastering, etc., for an item for walls, the doors and windows only being taken as extra value. This method gives a more accurate price than the cubing method, but should only be used for an approximate estimate.

Schedules. The use of schedules is for work the extent of which is not generally known, and consists of agreed prices for the various items of labour and material. The work executed is measured up on completion and brought into the form of an accurate bill of quantities.

Bill of Quantities. The preparation of a bill of quantities is the most satisfactory method of

obtaining a tender, and this should always be prepared on the instructions of the building owner. More satisfactory tenders are obtained for the work, and in the long run the building owner benefits, as if he does not instruct the architect to have quantities prepared, he very often has to pay the builder in the tender for preparing them, and if prepared to his instructions they will always serve as a basis for the adjustment of variations from the contract.

Meaning and Use of Specifications. The preparation of specifications for building work is very clearly linked up with that of the bills of quantities, and is often carried out by the quantity surveyor after he has prepared the bills from the drawings which have been supplied by the architect.

The general meaning attached to the specification is that of a detailed description with regard to the construction and formation of the building to be erected, and has generally application only to one particular set of drawings.

It should embody practically all the particulars of the contract entered into between the building owner and the builder, together with the relationship of the architect to both parties; the whole specification, together with the drawings, and sometimes the bills of quantities, forms part of the contract documents.

To be of real service it should be brief, but containing sufficient information for the parties using same to be quite clear as to the meaning and intent thereof. To obtain this clearness, care should be taken to use only the ordinary technical terms that are clear to tradesmen and workmen generally employed on a building, and all technical words seldom used should be avoided. It should be written in a definite order; each paragraph relating to an item should be carefully marked so as to separate the one from the other, and it is always a great service, both for inter-reference and reference by the builder, if the paragraphs are numbered.

Mention has already been made of a quantity surveyor writing the specification, but if it is not done by him, the person who writes it should be well acquainted with the ideas of the architect, and should also be quite familiar with the latest form of construction and materials likely to be used.

Where specialities of any particular firm are to be used, care should be taken to obtain, from their catalogue or price list, the correct description, and if possible, a catalogue number and prime-cost figure; but catalogue prices should not be quoted.

Writing a Specification. The best method of procedure for writing a specification is to outline on sheets of foolscap the general trade and sub-headings and items required.

It is advisable to keep a series of these sheets, so as to be able to refer constantly to what may be termed an outline for the preparation of writing up any new specification required; but it is a great mistake to cut and alter any old specification, unless great care is exercised in reading the description, or it will be found that paragraphs are included which do not apply to the particular job in hand, or which may contradict a description in another part of the specification.

The *heading* of the specification should consist of the title, showing completely the position of the job, and particulars as to the building owner and architect. The *preliminary clauses* should contain extracts from the form of contract, and which will be of service to the builder or the workmen, a list of the drawings, and also general information for the guidance of the builder carrying out the work.

The *body* of the specification should contain a full and accurate description of the materials and labour necessary for the job, this being divided up under the various trade headings, of which the following are the most general: Excavator and Concreter, Drainage, Bricklayer, Asphalter, Pavior, Mason, Tiler or Slater, Carpenter and Joiner, Ironmonger, Steel and Ironworker, Plumber, Plasterer, Glazier, Painter, together with such additional trades as Paperhanger, Heating and Ventilating Engineer, Electric Wiring and Bells, Gas Fitter, Coppersmith, Reinforced Concrete, Structural Steel and others.

It is of great service to everyone concerned if an index is made of the various clauses; and when these are numbered, as previously suggested, the finding of any required item is facilitated.

In writing the paragraphs, care should be taken to avoid any loose expressions which in particular throw the decision upon the builder. An expression such as "or equal," or "similar to," and also such expressions as "as required," "in a proper manner," are of no help to the builder. The writing should be quite definite as to the requirements of the architect.

It is advisable in writing a specification to

bear in mind certain of the rules laid down by the joint committee of the Surveyors' Institution and the Master Builders, and embodied in the *Standard Method of Measurement for Building Works*; for instance, the standard method gives certain rules for calculating the amount of lead at the eaves of a sloping roof, and also for the amount of passings to be allowed in connection with flashings, and, unless there is some particular reason, these allowances should be embodied in the specification.

It is impossible in the space available to give complete paragraphs for the whole of a specification required, but it must be borne in mind that in drawing up these various paragraphs instructions are being given to the builder for certain work, and the specification should be so worded that it is in the nature of a written order for what has to be done to complete the building; the paragraphs should, therefore, not read like a description from a bill of quantities, any more than a description in a bill of quantities should be like a paragraph from a specification.

When specifying that an item, such as a stove, has to be set by the bricklayer, remember also that the stove itself has to be mentioned in the Founder and Smith, and a note should be made in connection with the fixing, referring the reader to the paragraph where the provision of the stove is specified.

A point to be remembered in writing a specification is that it is not an instruction how to lay bricks or execute other work, but what is required by the architect to complete the job. The bricklayer knows how to lay his bricks, probably better than the architect, but will not know the architect's actual requirements in designing unless he is told.

In writing, if instructions are put into a concise form, they are more easily understood and carried out than if written up with numerous useless words. For instance, an item from a specification reads as follows: "The whole of the roofs to be framed together and constructed in the strongest manner, collars to be spiked to the rafters, and the rafters to the plates and purlins. In constructing the roofs, timbers of the following scantlings are to be used: plates 4 in. × 3 in., rafters and ceiling joists 4 in. × 2 in., ridges 8 in. × 1½ in., valleys 8 in. × 2 in., hips 8 in. × 1½ in., collars 4 in. × 2 in., purlins 5 in. × 3 in."

This extract can, it will be realized, be made much shorter and more easily understood by saying that the roofs are to be framed up and spiked, in the strongest possible manner, of the following scantlings—

Plates	4″ × 3″
Rafters and ceiling joists	4″ × 2″
Ridges	8″ × 1½″
Valleys	8″ × 2″
Hips	8″ × 1½″
Collars	4″ × 2″
Purlins	5″ × 3″

A clause in a specification which reads as follows: "Provide and build into all external openings suitable concrete lintels and provide all requisite board casings and struts, the lintels to be reinforced as necessary with ½-in. diameter steel bars," is not at all definite, and the sizes of these lintels and the number of bars required should be definitely stated to the various widths of openings.

Typical Paragraphs. It must be realized that the following typical paragraphs *are* only typical and that the examples do not form a complete specification; nor are all required in every case. They do, however, give an idea of the kind of paragraph that should be used.

The student can now begin the actual work of writing a specification, and will head it thus—

SPECIFICATION OF WORKS required to be done in the erection and completion of a house, at John Street, Smithtown, for A. B. Cee, Esq., in accordance with the drawings prepared by and to the satisfaction of

Messrs. DEE and ESE, F.F.R.I.B.A.,
900 Fore Street,
January, 19.... SMITHTOWN.

PRELIMINARIES AND GENERAL

1. **Contract.** The form of contract will be that agreed between the Royal Institute of British Architects and the National Federation of Building Trade Employers of Great Britain and Ireland, dated, 19...

2. **Site.** The site is situated in John Street, Smithtown, and adjoins the property known as "Brookwood"; the road is a public highway and the nearest station is Smithtown, about one mile away.

Possession of the site will be given immediately upon signing the contract.

The soil is believed to be gravel, but the contractor is advised to visit the site and satisfy himself upon this.

If approved by the architect the gravel and sand excavated may be used by the contractor, but the contractor is to pay to the building owner at the rate per yard cube which he would pay to a merchant for same.

3. **Completion.** The whole of the works must be completed and handed over within 26 weeks of the order to commence, or pay the building owner the sum of £5 per week as ascertained and liquidated damages.

4. **Drawings.** The drawings comprise—

No. 1. ⅛ in. scale plans.
" 2. ⅛ in. " sections.
" 3. ⅛ in. " elevations.
" 4. ⅛ in. " details.
" 5. – in. " block plan of site and drains.

And such other details as will be supplied from time to time.

5. Tools, Tackle, etc. The contractor is to supply all tools, tackle, and plant required for the due and proper completion of the work, and remove same at the finish of the contract.

6. Sheds, etc. The contractor is to provide all necessary storage sheds, mess rooms for workmen, and all attendance in connection therewith, and remove and make good any damage at the completion of the work.

7. Sanitary Conveniences. The contractor is to provide proper sanitary convenience for the use of workmen and others engaged upon the work, keep same in clean and sanitary condition, and remove and make good any damage on completion of the work.

8. Hoarding. Erect a close board hoarding along the front of the site next roadway, provide all necessary access doors, fans, planked footways and railings, all to the satisfaction of the local authorities, and remove and make good any damage on completion.

EXCAVATOR AND CONCRETOR

9. Clear Site. The site is to be cleared of all shrubs trees, or bushes, properly grubbing up the roots, and carting away or burning rubbish.

10. Surface Digging and Filling. Remove vegetable soil 6 in deep, and wheel and deposit it at spot where marked on site plan.

11. Trench Digging. Excavate for trenches to the depth shown on drawings, and of the following widths. for 9 in. walls, 2 ft. 6 in. wide; for 13½ in. walls, 3 ft. 3 in. wide. Level and consolidate earth at bottom.

The bottoms of foundations are to be approved by the architect before the concrete is laid.

12. Filling-in. All trenches to be filled in as soon as walls are above ground level. Use earth for filling where required to make up finished levels All filling is to be well punned in layers, and watered when so directed.

13. Pipe Trenches. Excavate for all water and drain pipes, and fill in and pun over same as before directed.

14. Surplus Earth. All surplus earth from excavations is to be carted away to a tip provided by the contractor.

15. Cement. The cement is to be British of approved manufacture, and to comply with the requirements of the latest specifications of the British Engineering Standards Committee, and if required by the architect a certificate to this effect is to be supplied with each consignment.

16. Lime. The lime to be freshly burnt grey stone lime, from an approved manufacturer, finely ground, and free from impurities.

17. Aggregate. The aggregate is to be clean, hard-broken bricks, stone or ballast.

Sand. The sand to be clean and sharp, and either fresh water or pit sand. No other sand will be allowed to be used. It must be free from clay, loam, dirt, and impurities, and washed or screened as necessary.

18. Concrete. The concrete is to be mixed on a clean boarded platform, by measure.

Concrete to be of the following proportions thoroughly incorporated and carefully deposited in position.

Foundations, and under floors and similar positions—

One part of cement.
Two parts of sand.
Four parts of aggregate to pass a 1¼ in. ring.

Lintels—

One part of cement.
One and one-half parts sand.
Three parts of aggregate to pass a 1 in. ring.

Casing to rolled sheet joists—

As for lintels but aggregated to pass a ½ in. ring.

BRICKLAYER

19. Mortar. The lime mortar to be composed of one part of lime to three parts of sand. Cement mortar to be prepared as required in small quantities, and to be mixed in proportion of one part of cement to three parts of sand.

20. Brick Walls. Build all walls throughout of the various heights and thicknesses shown and figured on the drawings, with all the projections, recesses, openings, etc., shown, in their proper positions. The footings of all walls to be of the number of courses shown, each course projecting 2¼ in. beyond the face of wall or footing immediately above same. To be built perfectly level, not to rake with the ground, but to be stepped up where the levels vary, as may be directed by the architect.

21. Brickwork in Cement. All brickwork in chimney stacks above roof level, all brickwork erected as piers standing alone, all hollow and half-brick walls, and such parts of the walls as are shown hatched on plans to be built in cement mortar.

22. Hollow Walls. The hollow walls shown on plans to be built in two half-brick thicknesses, with a 2 in. cavity, bonded together with wrought-iron galvanized ties, every 18 in. in height and 2 ft. 3 in. apart. The hollow and ties to be kept free of mortar droppings by haybands or battens lifted as work proceeds. The damp course to hollow walls to be laid at two levels, that over inner thickness one course above that over remainder. The perpends of external bottom course to be left open.

23. Facings and Pointings. The facings to be carried out in English bond, the perpends carefully kept, and the joints pointed at completion with a neat struck weather joint in grey-tinted mortar.

MASON

24. Rubble-walling. The walls of   to be built of local Kentish Rag from   quarry, squared and brought up to level courses not more than 2 ft. apart, and with not less than one through stone to each superficial yard. The face of stones to be left natural face, and joints pointed with V-joint in mortar.

SLATER

25. Roofs. Cover the roofs with best Portmadoc slates, 20 × 10 size, of first quality, laid to 3 in. lap on battens specified in "Carpenter," and nailed with two 1½ in. copper nails to each slate.

26. Ridges. Cover the ridges with 2½ in. rubbed slate bird's-mouth roll and 6 in. by ½ in. sawn slate wing, all bedded and jointed in oil cement, and secured with brass screws.

TILER

27. Roofs. Cover the roof with hard, well-burnt, approved red tiles of local manufacture, entirely free from fire cracks and other defects, laid to a 2½ in. lap, with two stout cast-iron tile pins to each tile and hung to battens; put tile and a half where required at edges and cuttings.

28. Hips and Valleys. Lay all valleys and cover all hips with purpose-made hip and valley tiles to course and bond with roof tiling.

CARPENTER

29. Materials. The timber generally is to be good quality, sound, bright, Baltic or White Sea red (or as is generally termed, yellow) or British Columbian Pine, and to hold the full sizes specified.

It is to be free from shakes and large, loose or dead knots, waney edges and other defects, and to be properly seasoned; no discoloured sap and only a small proportion of bright sap will be permitted.

30. Roofs. If the roofs are fully and clearly shown on the drawings, it may be sufficient to say—

Construct the roofs of buildings and the trusses of the sizes figured on the drawings. The rafters to be notched down upon purlins and cut true at the edges, and securely spiked thereto.

31. Gutters. Lay the gutters with 1¼ in. gutter boards and framed bearers to a fall of 1½ in. in 10 ft. with 2½ in. cross rebated drips not more than 9 ft. apart. The gutters to be 9 in. wide at the narrowest part. Form deal dovetail cesspools, 8 in. by 8 in. and 6 in. deep, for outlet of gutters, with proper dished and rebated perforation for 4 in. pipe.

JOINER

32. Materials. The timber for joinery is to be selected first or second quality Swedish yellow or first quality Petrograd, and is to be of approved brands, sound, clean, free from shakes, large, loose or dead knots, properly seasoned; no discoloured sap will be allowed and only a small proportion of bright sap.

The oak is to be of English growth.

[*Note.* Japanese oak is sometimes allowed, but American oak is only considered as equal to good quality yellow deal.]

The oak for internal joinery is to be Austrian wainscoat.

The mahogany is to be either Honduras or Tabasco.

The teak is to be Moulmein or other approved East Indian.

[*Note.* For large panels in joinery American white-wood, basswood, or Columbian pine may be specified.]

33. Windows. The windows numbered . . on plans to have deal cased frames, having 6 in. × 3 in. sunk, weathered, and check throated sills grooved on under-side, and to have 1½ in. × ¼ in. galvanized iron water bar bedded in white lead and let into groove in stone or brick sill, 1¼ in. pulley stiles, 1 in. inside and outside linings, ⅝ in. back linings tongued together, and the parting beads tongued to frame with 2 in. double hung ovolo-moulded sashes in six squares each, with sash bars 1¼ in. wide. Sashes to be double-hung with brass-faced axle pulleys, Austin's flax lines, and iron weights.

All double-hung sashes to have strong brass sash-fasteners p.c. .... each. Each lower sash to have a pair of brass sash-pulls, p.c. .... each. Sashes to have moulded horns, and deep bottom rail, with a beaded draught piece 4½ in. × 1 in. in place of bottom bead.

34. Doors. All doors numbered ... . on plans to be 2½ in. folding doors, each leaf four panelled, the top and bottom panels to have raised panels, and all to be moulded both sides. The frames to be 4½ in. × 4 in. rebated, chamfered, and moulded, and the doors to be hung thereto with one and a half pairs of 4 in. wrought-iron butts to each leaf. Put two 9 in. wrought-iron barrel bolts and a night latch, p.c. 10s. each. These doors to have 6 in. × 2½ in. architrave moulding, splayed at back for plaster. The pediment over door to be out of 2 in. stuff with moulded scrolls, as shown on detailed drawing.

35. Stairs. The stairs to have 1¼ in. treads with rounded nosings and inch risers glued, blocked, and bracketed on two 3½ in. × 2 in. fir carriages, 1¼ in. moulded outer string, 1½ in. moulded wall string, inch beaded apron linings, curtail step and veneered riser, 4 × 4 square framed newels, moulded handrail out of 3½ in. × 3½ in. selected wainscoat oak, 1¼ in. deal turned balusters housed to string and handrail. The newels to be wrought below landings, and turned as pendants 6 in. long. The wainscoat to be twice oiled with linseed oil at completion.

FOUNDER AND SMITH

36. Eaves Gutter. The eaves gutter to be 5 in. × 3½ in. cast iron moulded of stock pattern to architect's selection and to be properly bolted together in red-lead and fixed with galvanized mushroom-headed screws to the woodwork. All eaves gutters to have outlets cast on, and such stopped ends, angles, and other fittings as may be required. All outlets in eaves gutters to have strong galvanized iron wire domes.

37. Rain-water Pipes. The rain-water pipes to be placed where shown on the drawings, and to be 3 in. internal diameter, fixed to stand 2 in. clear of walls with clips and bolts. [*Note.* Or special "Melton" ears may be specified.] The heads of rain-water pipes to be of selected patterns, p.c. 10s. each. Each rain-water pipe to have any necessary offset or plinth bends, and shoe at foot.

HOT-WATER FITTER

38. Hot-water Supply. The domestic water supply is to be fitted up on the cylinder system in accordance with the following details, and is to be tested to the satisfaction of the architect before being approved.

39. Boiler. The boiler is to be a welded wrought-iron boot boiler .... in. metal, to hold .... gallons, properly set at back of range on firebricks to form flue under and at back of same, and is to be provided with manholes having cast-iron plates and screws. Particular care is to be taken that the manhole covers are absolutely water-tight.

[*Note.* The boiler as mentioned above is for a kitchen range, but under modern conditions an independent hot-water system is often installed with a special boiler in which case the specification would state—

The boiler is to be Messrs. .. .., No. . . , independent boiler, set in position and connected to brick flue with cast-iron smoke pipe having proper cleaning eye at elbow, and complete set of stoking tools. (If this is a large type boiler it may be covered with a composition insulation.]

40. Cylinder. The cylinder is to be a galvanized wrought-iron hot-water cylinder to hold .... . . gallons of . . in. plate, with wrought-iron manhole plate bolted over the manhole with gunmetal bolts, tapped and screwed with inside strengthening plate. The cylinder to be fixed in kitchen in position where directed on strong T-iron brackets, built into the wall. It is to be covered with an approved asbestos composition lagging, finished smooth and prepared for painting, and having necessary dishing to manholes.

41. Pipes. All the pipes for hot-water work to be wrought-welded, galvanized steam pipes, fixed 1 in. free from wall with steel clips screwed to deal, provision being made for expansion and contraction. No elbows but bends only are to be used.

The primary flow and return between boiler and

cylinder to be $1\frac{1}{4}$ in. pipes, the main circulation pipes $1\frac{1}{2}$ in.; the supply to bath to be 1 in., and to the lavatory basins and sinks $\frac{3}{4}$ in.

The cold-water supply to be brought from storage tank in —in. water tube.

In fitting pipes to boiler and cylinder, special care is to be taken that the boiler is fixed level, and that no pipes project into the interior of either the boiler or cylinder. The boiler is to be tapped and screwed for pipes, which are to have back-nuts screwed on outside.

Bell-hanger

42. Electric Bells. The conductors are to be not less than 1/·036 standard wire covered with a double layer of pure rubber, double cotton covered, and properly treated with paraffin wax.

Flexible wires to be not less than 10/·0048.

The wires are to be run in zinc or split conduit tubing concealed, of a size to avoid cramping wires, and having insulation as necessary to prevent abrasion.

Where staples are used they are to be insulated.

Provide all necessary blocks sunk in wall for fixing pushes.

The pushes are to be of an approved pattern having a screw top and properly insulated backs.

The batteries are to be of Leclanché type of sufficient size and number to properly work the system.

[*Note.* The bells may be worked off a transformer from the electric light mains in lieu of batteries.]

The indicator is to be of the pendulum type having glass front and enclosed in polished teak case with the names of rooms written in gold.

The whole system is to be left in proper working order with batteries charged.

[*Note.* It is better to give a schedule of bell points as—

Drawing-room.	Two pushes at side of fire.
Dining-room.	One ditto.
	One having loose plug and flexible wire in centre of room.
Bedroom No. 1.	One at side of fire and one pear push at bed.]

The pushes are to be of an average p.c. value of .... each to the selection of the architect, those to the outer doors to be of a water-tight description.

Plasterer

43. Materials. All laths to be "lath and half" thickness, butted at joints and to break joint every three feet, and nailed with iron nails.

[*Note.* If any metal lathing is to be used, specify thus—

Lathing throughout (or to so and so) to be metal lathing (give the make), fixed in accordance with the instructions of the manufacturers.

If rent laths are required substitute the word " rent " or " riven " for sawn.]

The lime to be fresh well-burnt stone lime, free from cinders, and to be run into putty at least one month before being used.

Portland cement to be of approved manufacture equal to the British standard specification.

The sand to be clean and sharp and to be washed if required.

Hair to be sound, long, black ox hair, well beaten up when dry and thoroughly incorporated with the mortar.

44. Coarse Stuff. Is to be composed of one part of lime to three parts of sand and 1 lb. of hair to be added to every 3 cub. ft. of mortar.

45. Setting Stuff. Is to be composed of one part of lime to two parts of washed sand.

46. Ceilings. The ceilings of . . to be lathed, plastered, and set, all the remaining ceilings to be lathed, plastered, floated, and set.

47. Walls. All inner faces of walls and half-brick partitions to be rendered, floated, and set, and all quarter partitions lathed, plastered, floated, and set. Render in cement and sand and set in fine stuff to all breeze partitions. The plaster to be continued behind skirtings. Walls of . . to be finished with dinged surface.

48. Angles. External angles are to be run in Keene's cement and have the arris slightly rounded.

[*Note.* One of the modern hard plasters may be specified in lieu of above, in which case the wording should comply with the maker's instructions.]

Plumber

49. Materials. The whole of the sheet lead to be the best new pig lead, properly milled and free from all defects, to be weighed whenever required at the contractor's expense, and equal to the specified weight. The contractor is to supply all necessary solder, copper nails, etc., required in laying leadwork. Solder is not to be used in fixing external leadwork, except where absolutely necessary. For securing edges turned into joints of brickwork, as in aprons and flashings, lead wedges are to be used, and joints are to be pointed in cement.

50. Lead in Flats and Gutters. Lay the flat over with 7 lb. lead laid to a fall of $1\frac{1}{2}$ in. in 10 ft., having $2\frac{1}{2}$ in. rolls, not more than 2 ft. 8 in. from centre to centre, and cross rebated drips not more than 9 ft. apart, as shown on plan. The drips in all cases to be $2\frac{1}{2}$ in. deep, and the ends of rolls to be properly bossed.

The gutters to main roof to be laid to a fall of $1\frac{1}{2}$ in. in 10 ft. with 7 lb. lead, 9 in. wide in narrowest part, and turned up under slating equal to a vertical height of 6 in., and dressed over tilting fillet.

51. Flashings. Where lead flat abuts against brickwork the lead is to be turned up 6 in., and have cover flashings 6 in. wide of 4 lb. lead turned into joints of brickwork 1 in.

Where the sloping edges of roof abut against vertical sides of dormer, put lead secret gutter 16 in. wide of 5 lb. lead covered with 5 lb. lead flashings 6 in. wide, with 4 in. laps. This flashing to be close copper nailed to boarded sides of dormer cheeks.

Where roof slopes abut against vertical faces of brickwork 4 lb. lead soakers are to be provided, one to each course of tiles (or slates), and having 4 lb. lead-stepped flashing 10 in. wide dressed down over tiles (or slates).

Internal Plumber

52. Lead Pipes. The pipes to be of the following weights per yard run—

These are the Metropolitan Water Board requirements for London, but local regulations must be followed.

Wastes—

$\frac{1}{2}$ in.	3 lb.
$\frac{3}{4}$ in.	5 lb.
1 in.	7 lb.
$1\frac{1}{4}$ in.	12 lb.
$1\frac{1}{2}$ in.	14 lb.
2 in.	18 lb.

The services and supplies—

½ in.	6 lb.
¾ in.	8 lb.
1 in.	12 lb.
1¼ in.	16 lb.

53. **Pipe Fixing.** All horizontal lead pipes are to be fixed on 1½ in. by 3 in. wrought and splayed fillets, plugged to wall, hollow groove on top side for pipe to lie in, and each to be laid with a fall towards the rising main, so that pipes may be emptied from draw-off tap at bottom of same.

(In many districts water pipes are of wrot iron or steel, galvanized or coated and the rules of the local water supply authority must be quoted in the specification in lieu of lead.)

54. **Supply Pipes.** Run supply pipes from cistern as follows—

[*Note.* Give a list of the supplies to be connected to cistern; when the pipes are lead they must be connected with a brass boiler screw and solder joint " full way " of the size of the respective pipes.]

55. **Lavatory.** Fit up the lavatory with Messrs. .... lavatory fittings as No. in their catalogue, including hot and cold supply taps, and plugs for waste p.c. £ .

The waste is to be 1¼ in. with drawn lead trap fitted with brass screw cap for cleaning. This waste is to be taken to discharge into slipper shown on plan (or into stack head or soil pipe).

Glazier

56. **Sheet Glass.** The windows number to . . on plans to be glazed with 26 oz. sheet glass of " seconds " quality.

The windows of scullery to be glazed with 24 oz. sheet glass of " thirds " quality.

The windows of larder and pantry to be glazed with 24 oz. sheet glass of " thirds " quality ground on one side.

Paper-hanger

57. **Hanging of Papers.** All walls which are to be papered are to be rubbed down, stopped, sized, and prepared for paper-hanger.

The walls of the following rooms are to be hung with lining paper before the wallpaper is hung—

Dining-room, drawing-room, etc.

All papers are to be butt jointed.

58. **Papers.** The wallpapers will be selected by the architect at the following p.c. prices, and the contractor is to add for preparing the walls, hanging, and profit—

Dining-room, 5s. per piece.
Drawing-room, 6s. per piece.
Bedroom (No. 1), 2s. 6d. per piece, etc.

Painter

Materials. In specifying the materials for the painter's trade it should be noted that the highest quality is not that described as " best."

There is a British standard specification for materials and ready mixed paints, and they may be required to comply with this.

The oil colours are to be prepared with genuine old white lead, pure raw linseed oil, and genuine American turps. The paint to be mixed on the premises, and all the materials to be tested, as the architect may direct, at the expense of the contractor. Each coat to be of different tint, and the finishing coats to be in approved tints.

It is very general to allow " ready mixed " paints to be used, and these when from one of the well-known firms are superior to any mixed on the job ; this will be specified as—

The paint is to be Messrs. . ... " Robolene " (or other name) delivered in the manufacturers' sealed cans and of proper under-coating and finishing qualities.

The exterior work is not to be proceeded with in wet, foggy, or frosty weather, or on surfaces which are not thoroughly dry.

All work is to be carefully prepared, and rubbed down between coats. Nail holes, crevices, cracks, etc., to be stopped with pure linseed oil putty after the priming coat is dry. All knots and sappy or resinous parts of the wood to be coated with two thin coats of best patent knotting, well brushed out.

All coats of paint, etc., are to be thoroughly dry before further coats are applied.

The wood is to be well rubbed down to a smooth face after each coat of colour ; and no coat of paint is to be followed by another until it has been seen and approved by the architect.

The internal woodwork to be painted as follows—

The woodwork in drawing-room and dining-room to be painted in four coats of oil colour to approved tints in party colours.

Woodwork of morning-room and smoking-room to be painted in four coats of oil colour, grained imitation walnut, and varnished with pale oak varnish.

Woodwork of offices to be painted in four coats of oil colour of approved tints and varnished with hard oak varnish.

Alterations. In specifying work that has to be done to carry out alterations, it is a great mistake to attempt to divide the work strictly into the several trades as is ordinarily done in specifying for new work. It is far better to specify the whole work connected with any particular piece of alteration, dealing with the work in all trades.

The description connected with each item should be split up into several paragraphs ; this is done to enable same to be more easily read and understood. It is very easy to get confused when reading a long paragraph containing description of work by several trades.

As it frequently happens in carrying out alterations that part of the premises only can be given up to the builder at one time, it is important to express clearly to what extent and at what times the builder will be allowed to have access to the different parts of the premises. There will, therefore, generally have to be some special clause defining the method of operations.

Chapter II—TAKING OFF: THE CARCASE

Introduction to Quantity Surveying. Upon receipt of instructions for the preparation of quantities, the surveyor should spend some time looking them over to obtain a mental picture of what they represent.

In this preliminary survey, notes should be made of questions which arise in his mind; the same idea of keeping notes should be followed during the period of *taking off*, a list being prepared for discussion with the architect before the bills are finally completed.

Whenever possible, a visit should be made to the site and any special feature noted, as also the description of the soil.

SYSTEMS. The general method of preparing a bill of quantities is that known as the *London system.*

The *Northern system* consists largely of the use of different units as the standard of measurement, the use of slightly different terms, and a general custom of each trade being tendered for separately, in many cases by different firms.

The *Scottish methods* are different again; the taking off is not the same, and there is no abstracting—but a proper explanation requires more space than is available here.

The London System. In the preparation of bills on the London system, the order of work consists of (1) "taking off," and (2) "working up." The various kinds of paper used are illustrated in the examples given, and will be understood if carefully followed.

When writing the dimensions, do not crowd them together; also use sub-headings to indicate sections, such as windows, doors, etc. Always use figured dimensions, but if there are none, figure the plans up before starting work.

Always take the largest possible dimensions, and make a deduction for wants or voids.

Any quantity of work which is uncertain, or is likely to be varied, should be made a "Provisional" item.

Measure in full detail; do not let the description cover a lot of items which can, and should, be measured.

The description should be full, leaving nothing to the imagination.

Make a practice of starting at a given point and working in a particular direction from the same. Do not jump about.

Book all the dimensions in the order measured, whether they are "adds" or "deducts."

Dimensions, except sizes of timber scantlings, are booked in full figures; fractions are not used.

When booking "half-brick" walls, book as "H.B.," but when booking an additional half-brick thickness to a wall, enter as "½ B."

If a wrong dimension has been booked, do not cross it out, but write "nil" against it in the third column, and when abstracting use a "wavey" line in cutting out the item.

Fractions are always booked as ½, ¾, etc., and not 1/2, 3/4, etc., which can be mistaken for shillings and pence or timesing.

Taking Off

ABBREVIATIONS. In taking off, it is customary to use abbreviations instead of writing the full description, and the following list gives some of those in general use—

a.b.	As before.	**L.W.**	Lime white.
a.d.	Average depth	**M.G.**	Making good.
B.	Brick.	**m/s.**	Measured separately.
B. & P.	Bed and point	**N.W.**	Narrow widths.
b/s.	Both sides.	**n/e.**	Not exceeding.
B.P.P.	British polished plate	**No.**	Number
B.N. & W.	Bolt, nut, and washer	**o/s.**	One side.
		O.G.	Ogee.
C.C.N.	Close copper nailing	**P. & C.**	Parge and core
Chy.	Chimney.	**P.C.**	Prime cost, or Portland cement.
Cir.	Circular.		
Ct. or C.	Cement.	**P.C.C.**	Portland cement concrete.
Ddt.	Deduct.		
Dia.	Diameter	**P.F.**	Plain face.
D.P.C.	Damp-proof course.	**P. & S.**	Planking and strutting
E.O.	Extra only.		
Exc.	Excavate.	**R. & S.**	Render and set.
F.F.	Fair face.	**R.F. & R.**	Return, fill, and ram
Frd.	Framed	**R.W.P.**	Rain-water pipe
Foots	Footings	**R.W. & P**	Rake, wedge, and point.
F.E.	Feather edge.		
Gal'd.	Galvanized.	**R.A.**	Relieving arch.
H.B.S.	Herring-bone strutting	**Sup.**	Superficial.
		T.	Tee.
H.B.	Half-brick	**W.I.**	Wrought iron.
½B.	Half-brick, but additional thickness only.	**W.o s.**	Wrought one side.
		W.b s.	Wrought both sides
		Xg.	Cross grain.
Lab.	Labour.	**Xtg.**	Cross tongued.
L.P.F. & S.	Lath, plaster, float, and set.	**2ce.**	Twice, etc.

Always take off and measure in a definite order and by a definite system.

There are two chief systems of taking off. One is taking off by "trades"; in this method the work is measured off the plans more or less in the order of the specifications,

each trade being completed before the next is attempted. But this system is not recommended even for the beginner.

The best system is the one in which the work is divided into three main divisions, comprising, (*a*) the carcase, (*b*) the joinery and finishings: and (*c*) the drains, sanitary work, fencing, etc.; and this is the system which will be followed. It has, of course, some disadvantages, among them being the necessity of completing the taking off before the work can be billed.

The general order for taking off is that followed in describing the method of measuring, and from this the student can compile a list of the order.

PREPARING QUANTITIES IN A BUILDER'S OFFICE. The subject of quantities is of interest to the student in a builder's office, because many estimates are required for which the ordinary bills of quantities are not supplied; in such cases, the architect asks for a tender by loaning to the builder a set of drawings and a specification. However, in certain districts the builders refuse to tender for work over a certain value unless quantities are supplied, the amount varying from £500 to £1000 or over.

Preliminaries. In beginning the "taking off," start with a heading to the first sheet of dimension paper, writing across the whole column as shown in the example. See Folding Plate, facing page 1600.

Notes only are made of preliminaries and preamble. The latter consists of the general description of the materials in the particular trade, and is written up from the specification when "billing."

On all sheets the name of the job should be written as shown.

CUBE OF BUILDING. The cube of building is a note made for information purposes.

ITEMS *ex* FORM OF CONTRACT. The form of contract which is being used should be stated; the items from the contract, which should be mentioned, are as follows—

The number of sets of drawings provided for the use of the builder.
Giving notice and paying fees to local and other authorities.
Setting out work.
Foreman.
Clerk of works' office.
Maintenance for certain period.
Damage to persons and property.
Insurance of various kinds.
Completion date.
Damages for non-completion.
Form of payment, etc.
Water for works.
Particulars as to site; also trial holes.
Provision of tools, plant, etc.
Sub-letting.
Testing materials.
Watching and lighting.
Removal of rubbish.

HOARDING, FANS, ETC. A linear dimension is given, stating the height, width, construction, etc.; also how long they are to be maintained, and if available for billposting.

Number gates and openings in same as extra only.

ADJOINING PROPERTY. This will follow the ordinary order for "taking off" as applied to the various classes of work to be executed, but is kept separate in the bill.

PULLING DOWN. As far as possible, work in pulling down is measured; only the small items should be numbered.

PARTY WALL. This is kept separate and taken off complete, and follows the usual order; but special work, as temporary screens and protective work, making good to floors, decorations, etc., is measured and, if considered necessary, billed as a provisional item.

Excavation. If possible, give the nature of soil in the description, and always keep rock separate.

The disposal of all excavated material is to be kept separate from the excavation, i.e. the "Bill" items would be similar to the following—

1. Yard cube: Excavate to surface trenches not exceeding 5ft. deep and get out.
2. Yard cube: Return, fill in and ram excavated soil to surface trenches.
3. Yard cube: Wheel 20 yd., load into carts and cart away surplus excavated soil.

SURFACE EXCAVATION. The excavation over the surface of the site, to remove the grass and garden mould, is taken by the superficial yard up to 12 in. deep, the depth being stated; when over 12 in. deep, it is taken by the yard cube. The surface excavation is measured over the area of the building, that is, from outside of the foundation trenches.

Surface excavation also includes work other than the removal of turf and garden mould, such as levelling the site for building, when the whole area has to be excavated to a definite level ready for building.

In measuring excavation, it is the net quantity previous to excavation that is billed; and no allowance is made for the increase in bulk.

PLANKING AND STRUTTING. This should be measured; expressions such as "and including all planking and strutting required" must not

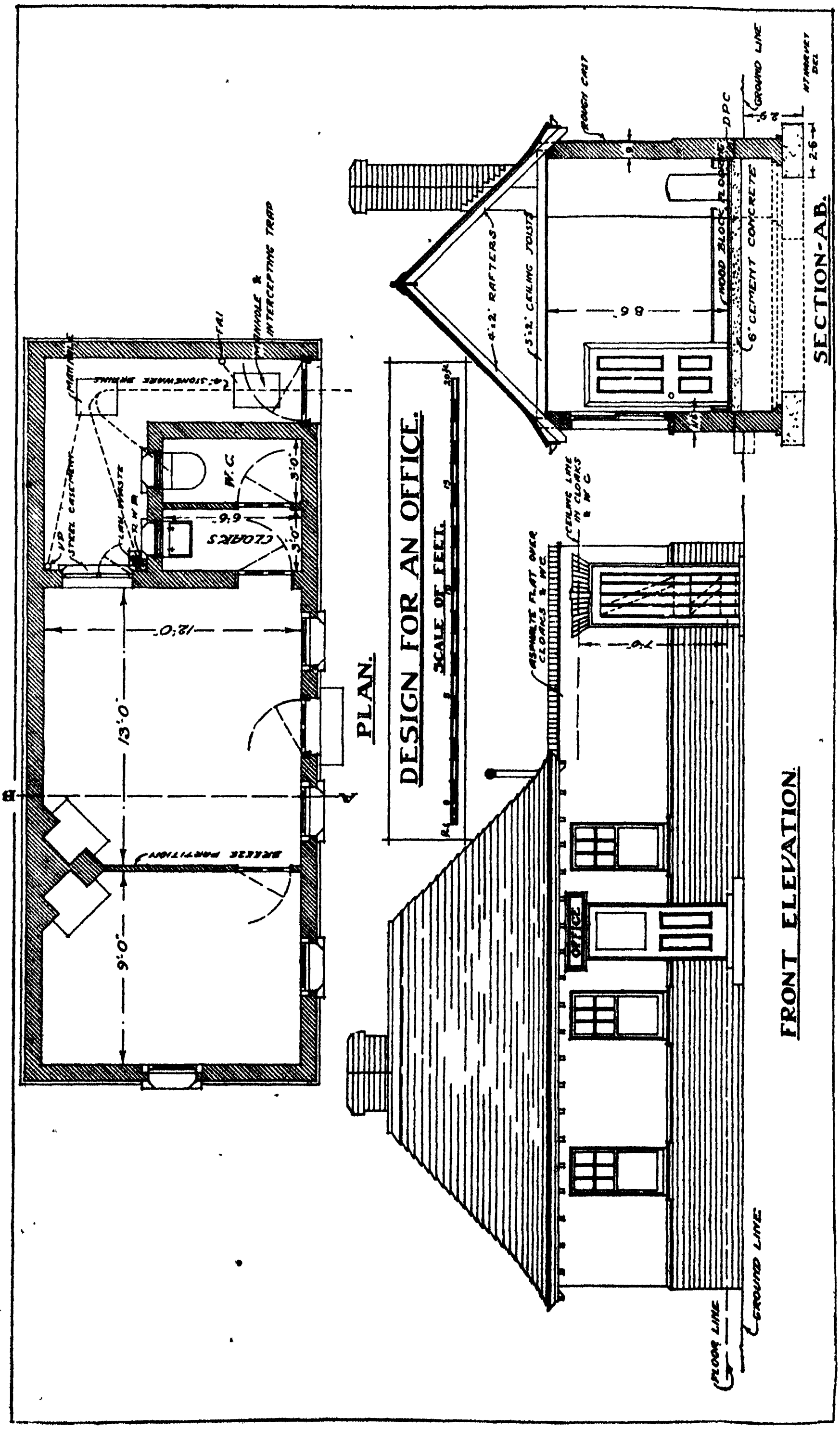


Plate I. Quantity Surveying

be used. The area of the whole face of the excavation is measured, and it is better to treat the ordinary trench excavation in the same way, but mention should be made that both sides are measured.

It is only the face of the excavation that is measured, not struts, waling pieces, etc.; these are allowed for in the price.

Tunnels are taken as linear, giving the width and height. Where any timber has to be "left in," keep it separate.

BASEMENT AND TRENCH EXCAVATIONS. These are cubic dimensions; the excavation is kept separate in depths of 5 ft., to allow for the extra labour in working from stages.

Basement and ordinary surface trenches are kept separate. The depth at which the basement trench excavation starts should be mentioned.

A certain proportion of the excavation is generally returned and filled in to the foundations, and this is kept separate.

A dimension should be taken for preparing bottom of excavation to receive concrete, or a note made that the excavation includes this; the former method is the better.

Excavation in pier holes is kept separate. In all excavation work an item is included for pumping, to keep the excavations clear of water.

EXCAVATIONS TO CUTTINGS. Excavation for cuttings, forming embankments, etc., is measured by the cubic yard, but with work of this nature state how the excavation is to be carried out.

Sides of excavations which have to be battered, and surplus soil spread and levelled over a surface, or formed into slopes, are taken by the yard superficial for the labour.

Where the work of excavation is likely to encounter trees, shrubs, roots, etc., this is mentioned, and if possible these items are numbered for removal.

CONCRETE IN TRENCHES. Take this by the cubic yard, and separate the basement and surface trenches. If less than 12 in. thick, mention this in the description.

EXAMPLE I. Sheets Nos. 1, 2, and 3 show a typical example of the method of booking, on dimension paper, the dimensions for excavation, concrete, and brickwork. These sheets are reproduced to a scale of half size from the actual taking off sheets, the dimensions being taken from Plate I.

It will be noticed that the dimension is written in the second column, which is called the *dimension* column; and where it is desired that the item shall stand for another similar item it is *timesed* in the first, or *timesing*, column, as will be seen on sheets Nos. 2 and 3.

The collection of different dimensions on waste, which is the fifth column, will be observed.

It will be noticed that at the bottom of the left-hand principal column of sheet No. 3, an item has the word "nil" written against it; this illustrates what is done when an item is wrongly entered.

THE CARCASE

Brickwork. Brickwork in London is measured and booked as a superficial dimension of brick dimensions, and is reduced to the standard rod on the abstract. For the Midlands and the North, it is often reduced to the superficial yard, one brick thick, unless over 3½ bricks thick, when it is given in cubic yards.

All brickwork is measured as being built with ordinary bricks, and work built of other bricks is deducted and added as work in these or an "extra only" item taken.

The general height of the brickwork should be stated.

Work of odd sizes or shapes is measured cube, and reduced to standard on abstract.

In measuring internal walls, the dimensions for the excavation, concrete, and footings are reduced in length by the projection of the main walls.

WORK KEPT SEPARATE. The following items should be kept separate—

- One-brick walls faced both sides.
- Half-brick walls.
- Garden walls.
- Brickwork in small quantities, for making good, or for filling in old openings.
- Brickwork which is much broken up with piers; this increases the labour.

Always keep separate any work which involves additional labour, or which is of a cheaper character, such as—

- Heavy work in foundations.
- Retaining walls.
- Deep foundations, or trenches.
- Brickwork in backing to masonry or a super item taken to cover this, the brickwork being included in the general item.
- Brickwork in cement.
- Work built off girders and in raising old walls stating the height above datum.
- Walls built to a batter or with a battered face.
- Work circular on plan.

This last item has the radius stated as "to flat sweep" over 6 ft. radius, and "to quick sweep" under 6 ft. radius.

Where brickwork is built off steelwork, an item is given for scaffolding, the height at which the work starts being mentioned. This item does not apply to a steel-framed building.

Design for an Office Building as Drawings shown on Plate. I.

May 19

Preliminary Works. B/B.

Preambles. B/B.

9		9
9		12 0
13 0		9
9		
3 0		
3 0		
9		
3 0		
9		
36 9		13 6
2 ... 1 9		1 9
35 6		15 3

36 6 / 15 3 — Exc. T/S ave. 6" deep & D.O. Wheel & Dep. n.e. 2 runs, cubed by 6"

N wall		36 9
E		12 0
		48 9
2		97 6

2/ 2 9 / 6 / 2 3

93 6 / 2 6 / 2 3 — Exc. to S.T. in clay soil. & R. F & R.

93 6 / 2 6 / 1 0 — Ddt. R F & R & add W & CA. & P.C.C. (1 3 6)

1 6 / 1 7½ / 2 8 / 1 6 — Fnds.

93 6 / 1 4 / 6

93 6 / 9 / 9 — Ddt. R F & R & add W & CA.

adjust for R F & R to Surface

36 6 / 13 6 / 50 0 / 2 = 100 0

100 0 / 9 / 6 — Ddt. W & D. n.e. 2 R & add R.F. & R. to Founds

Design for an Office Building Sheet 2.

36 6 / 15 3 / 51 9 / 103 6 / 103 6 / −8 = 20 0 / 83 6

103 6 / 2 9 — P & S to S.T. b/s read.

83 6 / 2 3

93 6 / 2 6 — Pp bot of S.T. for P.C.C.

Bk wk to D.P.C.

93 6 / 6 — 1½ B wall in Fnds.

93 6 / 1 9 — 1 B ditto to D.P.C.

93 6 / 9 — 2 Cs slates in Ct laid breaking jt as D.P.C.

Int Walls to D.P.C.

Wall between Office & W.C.

12 0 / −2 = 1 9 / 10 3

10 3 / 2 6 / 2 3 — Exc. to S.T. & D.O. a.b. & R F & R

10 3 / 2 6 / 1 0 — Ddt. R F & R & add W & CA a.b. & P.C.C. a.b.

12 0 / 4 / 11 8

11 8 / 1 4 / 6 — Ddt. R F & R a.b. &

12 0 / 9 / 9 — add W & CA a.b.

2/ 10 3 / 2 3 — P & S to S.T. a.b.

2/ 2 6 / 2 3 — Ddt. — Junc. Returns

10 3 / 2 6 — Pp bot of S.T. for P.C.C.

11 8 / 6 — 1½ B a.b.

12 0 / 1 9 — 1 B a.b.

12 0 / 9 — D.P.C. a.b.

Design for an Office Building Sheet 3.

Walls W.C.

3 0 / 4½ / 3 0 / 9 / 6 6 / 13 7½ / −2 = 1 9 / 11 10½

11 11 / 2 6 / 2 3 — Exc. S.T. a.b. & R F & R

11 11 / 2 6 / 1 0 — Ddt. R F & R & add W & CA a.b. & P.C.C. a.b.

13 7½ / 4 / 13 4

13 4 / 1 4 / 6 — Ddt. R F & R a.b. &

13 8 / 9 / 9 — add W & CA a.b.

2/ 11 11 / 2 3 — P & S to S.T. a.b.

11 9 [illegible]

11 11 / 2 6 — Pp bot of S.T. for P.C.C. a.b.

13 4 / 6 — 1½ B a.b.

13 8 / 1 9 — 1 B a.b.

13 8 / 9 — D.P.C. a.b.

½ B wall or Partition taken off Surface P.C.C.

Bk wk to Frame

93 6 / 12 0 / 105 6

9 / 9 / 13 0 / 9 / 23 10½ / 12 0 / 35 10½ — 2 = 71 9

71 9

71 9 / 9 3 — 1 B in Lime, ... a.b.

33 9 / 9 3 — Wall ... Frame

13 8 / 7 9 — W.C.

71 9 — B.F. to 1 B wall

For plinth see ...

another similar item it is *timesed* in the first, or *timesing*, column, as will be seen on sheets Nos. 2 and 3.

the work starts being mentioned. This item does not apply to a steel-framed building.

When an additional thickness of new work is added to an existing wall, ordinary bricks being used for bonding, a quarter brick is added to thickness; the tooth and bond is included in the superficial item for extra thickness.

"Toothings," or "indents," left for the connection of future walls are taken as a linear dimension for the thickness of wall.

UNDERPINNING. Work in underpinning is kept separate and described as being in "short lengths in underpinning"; the excavation and concrete are also separated.

Mention that the work is in lengths not exceeding 4 ft., and take a width of at least 3 ft. from the face of the wall for excavation up to 5 ft. deep, 4 ft. 6 in. wide from 5 ft. to 10 ft. deep, and 6 ft. wide over 10 ft. deep. An item is also taken for wedging up to the old wall for the joint between old and new work.

Cutting off old footing courses should be taken as a linear dimension, but cutting away the old concrete can be cubed. All underpinning will require an item for the necessary shoring, needling, etc.

HOLLOW WALLS. Take off the brickwork in the ordinary way; that is, if it is an 11 in. wall in two half-brick skins, measure a superficial dimension of one-brick wall. This brickwork should be kept separate as "in hollow walls" or "in half-brick walls forming inner and outer skins to hollow walls," and the same dimension will answer for an item for the extra labour in building in two half-brick skins, and for the value of wall ties and building in.

CUTTINGS. Rough cutting is measured by the foot superficial, and is generally only measured when raking or circular. If fair cutting has also to be measured, a deduction is made from the rough cutting equal to 4½ in. wide, this being the width allowed for fair cutting. Fair cutting is a linear dimension taken to facing work.

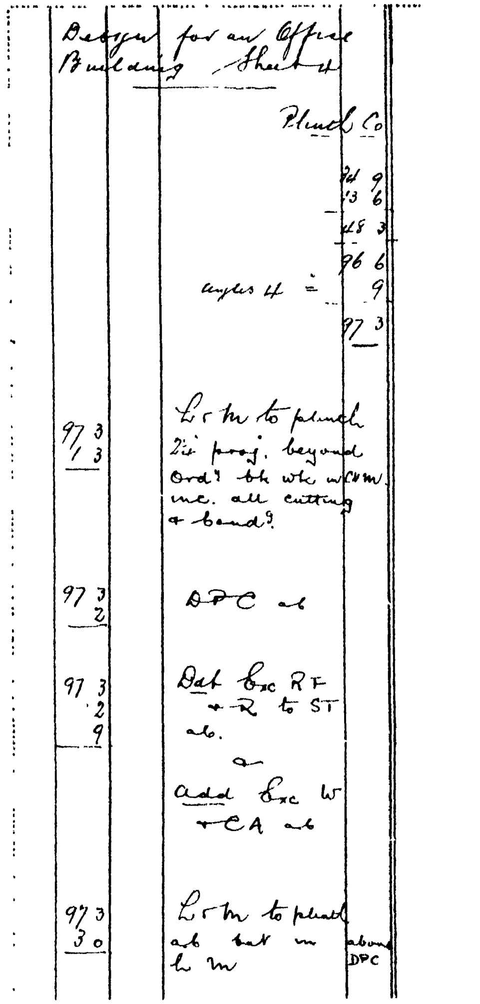
Other rough and fair cuttings are bird's-mouth and squint quoins, both being linear dimensions.

Fair rounded, or bull-nose, angles and fair splay angles have the girth and width stated.

DAMP-PROOF COURSE. Measured per foot superficial, except 4½ in. and under in width, when it is taken as a linear dimension.

Vertical work is kept separate. It will require additional "excavate, return, fill, and ram" to allow for working. This is taken to make a total distance from the face of brickwork to face of excavation equal to 2 ft. Where the top edge of vertical work is turned into the brickwork, an average of 1 in. is added to the height, and an item taken for "raking out and pointing."

At the junction of vertical asphalt with any horizontal damp-proof course which is at lower


Design for an Office Building Sheet 4
Plinth Co
24 9
23 6
48 3
96 6
angles 4 = 9
97 3
97 3 / 1 3 — L c m to plinth 2¼ proj. beyond Ord^y bk wk in c m inc. all cutting & bond^g
97 3 / 2 — DPC ab
97 3 / 2 / 9 — Ded Exc RF & R to ST ab. & add Exc W & CA ab
97 3 / 3 0 — L c m to plinth ab but in L m — above DPC

TAKING OFF, EXAMPLE 2

edge of same, and which has to be joined to it, an angle fillet is measured to make a watertight joint, and unless there is an offset course of the footings to take this, a single projecting course is measured.

External angles of vertical work have a linear dimension for "labour to rounded angle."

PLINTHS, ETC. A plinth is sometimes formed by building the lower portion of the wall of greater thickness than the general walling, but

is often formed by an additional thickness of quarter-brick added at the base of a wall, and built from the topmost course of footings. This last is measured as a superficial item for additional labour and material in quarter-brick as plinth. If a multiple of half-brick, it would be added to the ordinary brickwork; but if, say, it is three-quarter-brick, then the material is added to ordinary brickwork, and a superficial item taken for the additional labour in rough cutting and waste on bricks. The splay course at the top is measured as "extra for one course purpose-made, red, sand-faced, splay bricks as plinth course including pointing"; the mitres are numbered.

EXAMPLE 2. The dimensions shown on sheet No. 4 illustrate the method of booking a plinth projection, when it is less than a half-brick in thickness, and the various adjustments in connection therewith.

HOOP-IRON AND OTHER BONDS. These are measured by the foot or yard run, and the gauge and width stated; the total weight is also given.

BEAM FILLING. This is measured round the eaves as a linear dimension for the extra labour, stating the thickness of the walls; the brickwork is included in the height of walls.

PROJECTIONS TO ORDINARY WALLS. After measuring the ordinary wall, projections, such as piers, are measured.

CHIMNEY BREASTS. These are now taken off complete, including excavation, concrete, brickwork, and facings, as shown in Example 3.

The chimney stack is measured with the breast, but the chimney-pot and work to head should be left until the "fires" are taken off. This brickwork is added to the ordinary reduced work.

EXAMPLE 3. Sheet 5 illustrates the work in connection with the item for chimney breasts; see Fig. 1. It will be noticed that none of the finishing work in connection with these is booked at the present moment.

Steelwork over Voids. Portions of upper floors are sometimes carried over yards and open spaces upon R.S.J.'s, supported by either R.S.J.'s as stanchions, or by iron or steel columns. These are measured complete; the excavation, concrete, etc., is taken in the usual way, but kept separate in stanchion bases. Keep separate the concrete where it is packed round grillage.

The stanchion and girders are taken in detail to enable them to be "weighted out." An ordinary sectional R.S.J. not cut to a dead length is measured to the next foot, and no cut taken. If it has to be cut to a dead length, a cut is taken as a numbered item.

The net weight is taken, no allowance being made for rolling margin.

A compound, or built-up, girder is measured net and the cut numbered, an addition being taken for the weight of rivets. This will increase the weight between 2½ to 5 per cent; but when taking off from a steelwork drawing, the number can generally be calculated and the correct weight booked.

Solid steel columns have the number, lengths, and diameter given in the description, and the caps and bases are numbered. The description should state whether they are shrunk on or fixed by some other method.

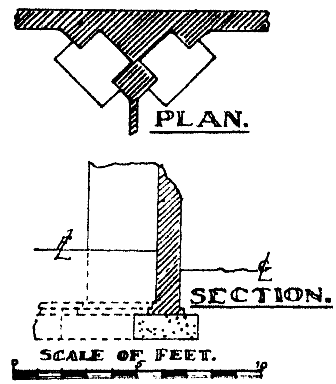


FIG. 1

Sundries to the steelwork–as forgings, angle cleats, and other connections, holes for bolts, distance pieces, rag bolts, the holes in stone or concrete bases, running same with cement or lead—are all numbered. No deduction is made for bolt holes.

Masonry. Templates and Base Stones are taken by number and the labours are included in the description.

COVER STONES are measured by the linear foot when less than 12 in. wide, and by the superficial foot when over this width, the finish of the surface being included in the description; the ordinary straight self-faced edge is included. Tooled or rubbed edges, when stone is measured superficially, is by the linear foot, giving the thickness of stone; and if the stone is grooved for the rivet heads, this is taken as a linear dimension, any notchings being numbered.

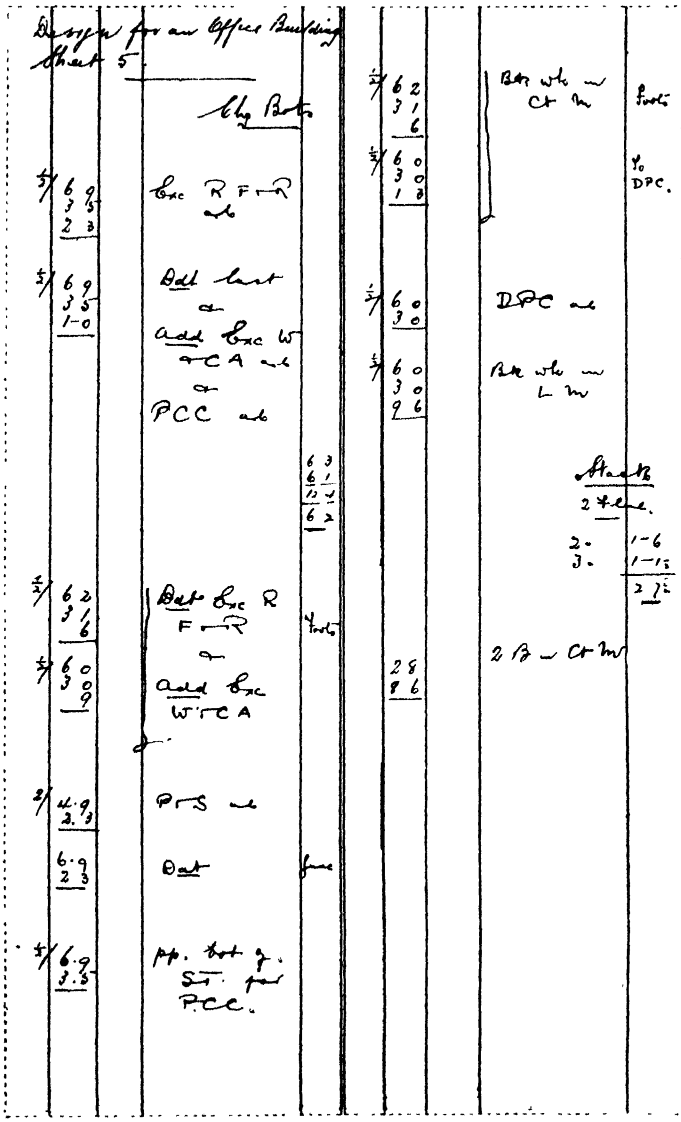
Painting on steelwork is taken by the superficial yard.

The work now measured is not to ordinary openings in walls having R.S.J.'s, these being included in due course under openings.

FACINGS. These are measured as a superficial dimension over the whole surface exposed, and the height is taken from 3 in. below the finished ground line. This item is for the extra value

over the ordinary bricks used in the wall, and for pointing with the particular joint specified.

White glazed facings are measured in a similar manner, but, for all internal angles, a



TAKING OFF, EXAMPLE 3

linear dimension is taken for cutting and waste. A linear dimension is taken for each external angle for plumbing angles.

Walls 9 in. or less in thickness, when faced both sides, are not included in the ordinary brickwork and the facings measured separately; but are taken as a superficial dimension for the wall, stating thickness and that it is faced both sides with facing bricks.

EXAMPLE 4. Sheets 6 and 7 show, for the job shown on Plate I, page 1599, the method of entering the dimensions for the facing work, which is measured as an additional value over the common brickwork, or as an item on its own, as in the case of the rough cast shown.

QUOINS. Angles of a building faced with quoins formed in different brick to the general facing, or in rubbed and gauged work, are measured as a linear dimension, and the description states the average width, and whether flush or projecting. In the latter case, the projection is stated and the item includes the additional material. Edges of quoins chamfered or moulded are measured as a linear dimension for the labour; mitres, stop ends, etc., are numbered.

If quoins have a straight joint with the ordinary facing, a linear dimension for cutting and waste is measured.

STRING COURSES, BANDS, ETC. When measuring the facings, extra brickwork, or additional value to brickwork, for these is measured.

The work is measured on the same basis as that given for plinths; but when in plain bands, four courses or less in height, or oversailing courses, a linear dimension is booked for the labour and materials, and all mitres and stop ends are numbered.

MOULDED COURSES, if of purpose-made bricks, are booked as labour and material, stating the maker's name and catalogue number.

Fair cutting at contact with any raking or circular portion is measured as a linear dimension.

TILE HANGING is measured by the square, or yard superficial, togethers with battens for fixing; these latter are kept separate. No deduction is made of less than 4 ft. super.

The bottom course has a double eaves course and is tilted, having either a course of brick set projecting, or splay fillet fixed to wall. The ordinary cuttings taken for roof tiling are also measured to vertical work.

ROUGH CAST, RUSTICATED, AND PLAIN FACE in cement and sand are measured by the yard

super, but where less than 1 yd. super, or 12 in. in width, are described as in small quantities or narrow widths respectively; and if 6 in. or under in width are taken at per foot run.

Quoins which are "rusticated," or "vermiculated." have this measured as a extra value over the other work, which is first measured.

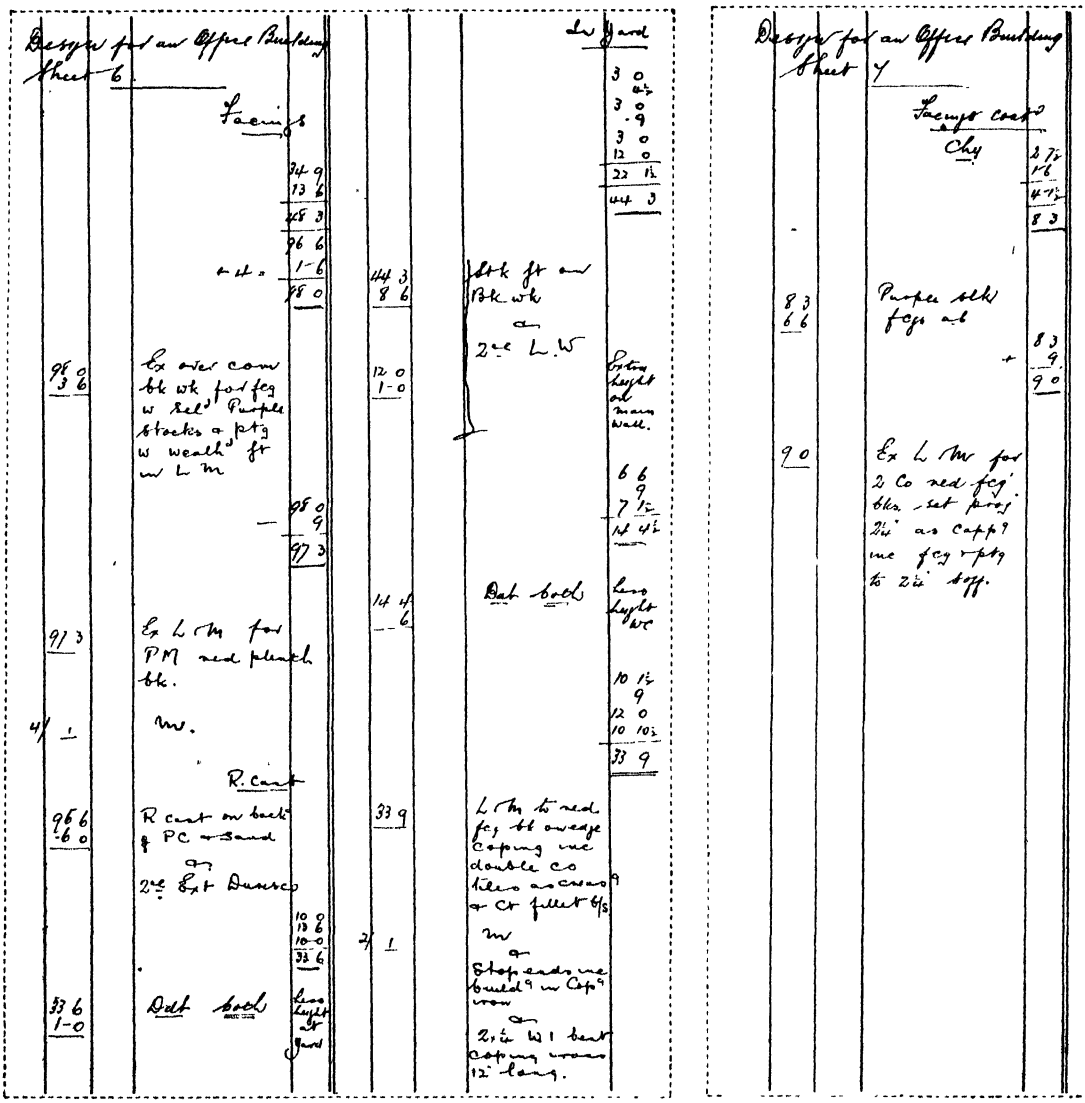
No deduction is made for less than 4 ft. super.

Arrises, quirks, grooves, and rounded internal and external angles are taken by the linear foot, with mitres, etc., numbered.

A cove or a weathering is a linear dimension.

MOULDINGS run in cement facing and dubbed out have this mentioned in the description, but large projections are generally formed on a core of brickwork, which will be measured separately, with any rough cutting required.

TERRA-COTTA, FAIENCE, AND ARTIFICIAL STONE. Measure these by the cubic foot under the headings of "Plain," "Moulded and Splayed," and "Moulded and Enriched" work. Enriched work by artists is kept separate. The



TAKING OFF, EXAMPLE 4

hollows in terra-cotta are filled with fine concrete either before or after fixing, and the description must include for this. Moulds are included in the description. The work is kept separate in heights of 20 ft. after the first 40 ft. Measure items for cleaning down, straightening grooves, ends cut and pinned to brickwork, cramps, dowels, etc.

BRICK-ON-EDGE COPING. Brick-on-edge coping is measured as a linear dimension for bricks set on edge as coping, and the thickness of wall stated. Mitres are numbered, and ramped or irregular work is kept separate.

Coping irons are either numbered or measured for weighting out, and an item taken for building in.

If the coping has a double course of flat roof tiles built in under, this is measured by the linear foot, and the thickness of wall stated.

It may often be better to take this type of coping complete and include all the items together; the brickwork is only measured to the underside of the tiles.

Special coping bricks and terra-cotta are taken as a linear dimension, with all mitres and stopped and returned ends numbered.

Give a full description of the size and shape, and, where possible, the maker's name and catalogue number.

Take dressed-stone copings by the linear foot, with the various labours included in the description, except mitres, etc., numbered for extra labour.

STONE STRINGS. Stone strings are taken by the foot run, including labours, but the width of bed is always stated, and brickwork is deducted for the portion in the wall; number mitres, fair and return ends, etc.

DRESSINGS. Measure cube with full description of labours, keeping special stones separate.

STONEWORK GENERALLY. This is measured by the cubic foot, with a full description of the various labours and is kept in groups of among others—

Pilasters and Quoins.
Caps and bases to pilasters.
Jambs.
Lintels.
Springers.
Voussoirs.
Columns.
Caps and bases to tost.
Large cornices and string courses.
Angle stones to tost.

ASHLAR WORK. Ashlar work, which consists of a thin facing of stone to the walls, is measured by the foot super, and the dimension includes all labours; the description must give the average thickness of bed, the number of bond stones required, and whether the courses are regular or not. From this work, all special features and windows and other openings must be deducted, and the stonework to them measured separately.

RUBBLE WALLING. This is measured as a cubic dimension where over 18 in. thick, and reduced to cubic yards; but where of less thickness, it is measured as a superficial dimension in the various thicknesses, and the description gives the type of walling.

The foundations are cubed and kept separate, piers are taken as linear dimensions.

Chimney-stacks are cubed but kept separate.

Rubble walling with a backing of brickwork has the number of bond stones per yard stated.

Internal angles formed in a solid stone are measured by the linear foot.

Facing of the same stone as the wall is taken as "extra only," the description giving full particulars as to the type of facing and the average bed.

A linear item is taken for labour to angles.

Drafted edges to angles are included in the description.

Dressed stone used in rubble walling, if in small quantities, is measured as "extra value" over the walling; but it is better to take a deduction from the rubble and measure the cube stone as before stated.

DRESSED MASONRY. All dimensions are the net size of the block of stone from which the particular section can be obtained. Single blocks over 40 ft. cube are kept separate in every 10 ft.; and except in the case of spandril steps, it must not be assumed that two stones can be obtained from one piece.

For stone over 6 ft. long, keep separate and state the length.

Stonework hoisted over 40 ft. has an item for extra hoisting mentioned.

Stonework to be measured in feet run consists of small cornices, string courses and the like, sills, copings, mullions and transoms. In connection with the last items, angle stones, kneelers, etc., are numbered.

Stoolings are numbered.

Items numbered are balusters, finials, caps and bases to pilasters and similar.

Labours to be measured separately are grooves, fluting and similar items; these if stopped must be described and the stops

numbered. Where these labours are on stone measured by the foot run they are included in the description.

Stone fitted to Steel. An item in feet run is taken for the sinking, notching, etc., to steel.

CARVING. Where this has to be done, the stone must be measured of sufficient size, and a superficial item taken as "boasted for carving," and for the labour in carving a provisional amount is inserted, as also an item for scaffolding, tarpaulins, etc., for the carver.

Ornamental bands, such as bead and reel, egg and dart, dentils, etc., are worked by the mason and are measured by the linear foot, and small pieces numbered.

Numbered items are booked for making good ends of mouldings, etc., up to carving.

SUNDRIES. Copper cramps, lead dowels, etc., are numbered and described.

All mitres, stopped ends, returned mitred ends, holes, dowels, etc., in connection with all items are measured.

An item is taken to provide for protection to stonework.

LEAD COVERING. Sheet-lead covering to cornices is measured and weighted out. An item for groove in the stone to receive the edge of the turn-up, together with an item for burning in the lead and pointing, is taken as a linear dimension.

At about every 3 ft. lead plugs, for fixing, are measured as numbered items, including the dovetail hole in stone.

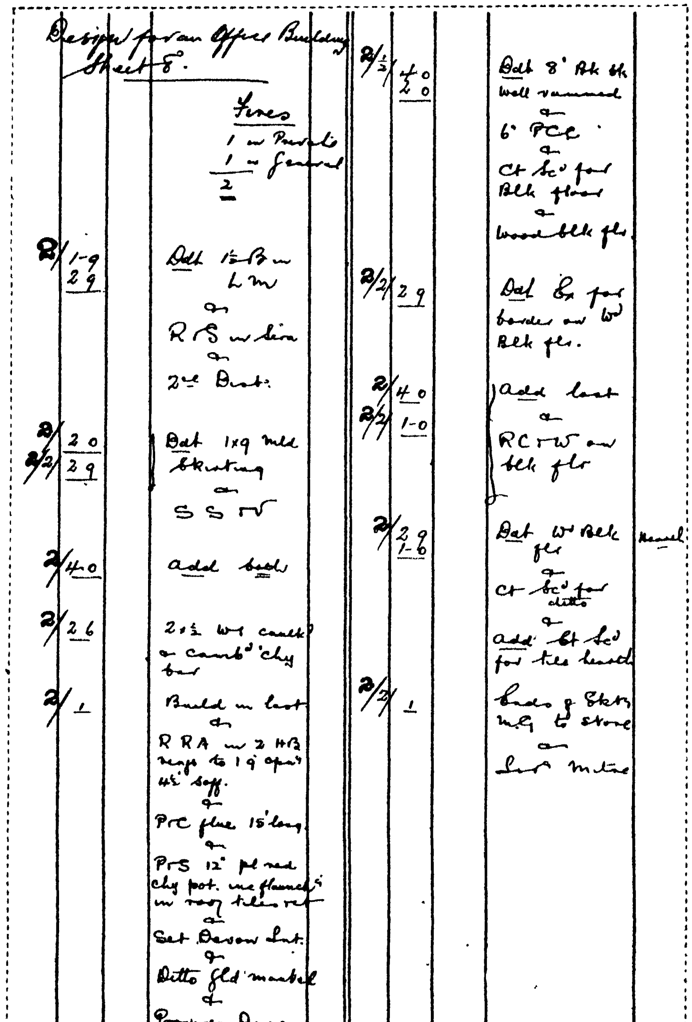
Welted Joints are measured to each length of lead, by the foot run for extra labour, and an additional 4 in. is added to the length of lead for each joint.

CORNICES, formed of moulded bricks, are measured as a linear dimension as extra only on brickwork, stating the maker's name and catalogue number, pointing being included. The description should give full particulars as to the number of courses in height and the girth of the moulding.

Stops, mitres, etc., are numbered.

A deduction is made for the ordinary facing displaced.

Areas, Coppers, etc. All work will follow the methods described, with the addition that, if the walls of areas are built with a battered face,



TAKING OFF, EXAMPLE 5

an item is taken by the superficial foot for the labour in rough cutting, and the description states the amount of batter per foot of height.

Walls built battering have the whole wall kept separate. Weep-holes are numbered.

Wrought-iron gratings and railings are mea-

sured for weighting out, labours to forged and split ends, twists, etc., being numbered; but cast-iron railings are taken by the foot run, with particulars.

Fires. The work to chimney breasts will now be completed. Additional excavation, concrete, etc., to ground floor for hearth and fender wall is added to ordinary item. Filling to hearth is cubed. The concrete to hearth is supered.

Deduct from the brickwork for the fireplace opening; no deduction is made for the flue. Deduct the wall plastering (unless under 4 ft. super) and also distemper or paper. Take an item for making good plaster to chimney piece.

The chimney bar is taken by the linear foot for weighting out.

Book an item for building in. The rough relieving arch is numbered for the size of opening and number of rings stated. Parge and core flue, provide and set chimney-pot, setting the stove, fixing mantelpiece, blacking stove, and painting mantelpiece are numbered items. The hearth will give the deduction of flooring and the addition of hearth. With tiles, take an item for screeding; the mitred border to the flooring is measured by the foot run.

Upper floors require trimmer arch, measured by the foot super as "half-brick trimmer arch," or numbered, giving the dimensions. Take items for fine concrete filling and centering to trimmer arch; this latter, when left in for lathing, should have this mentioned. The rough splay cutting for the arch and feather edge springer spiked to joists are taken by the linear foot. The rough render on the brickwork, where passing through the floor joists and roof timbers, and also to chimney backs, is taken by superficial feet.

Upper hearths, when formed of reinforced concrete, will require centering on their soffits and provision for keeping in position.

Skirting and similar items are deduced to fireplace opening.

EXAMPLE 5. Sheet 8 shows the completion of the work in connection with the fires, and there is now booked the whole of the finishing work in connection with the chimney breasts.

It will be noticed that there are two fires, which are exactly similar; instead of booking them twice the whole of the items have been "twiced" in red ink, which in this case is illustrated by the heavy 2 shown on the sheet.

Pavings. Excavation is measured as for ordinary surface excavation. Rubble, or stone filling, is taken by the yard super, stating the thickness. The concrete is measured by the yard super, stating thickness. The finished paving, whether in the form of granolithic, ordinary cement and sand, tiles, bricks, marble, slate, asphalt, artificial stone, slate, or York stone slabs, is measured by the yard super. The description in the case of the first two pavings should give particulars as to the finish, and in the latter the method of laying.

For tiles and marble, the description must give full information as to kind and pattern, also how laid, and an item must be taken for screeding in cement and sand to receive them.

When a paving is laid to falls, this must be stated and kept separate.

Temporary boarding to the edge of concrete is measured by the foot run, stating the depth.

Edging to the paving is taken by the foot run, giving full description.

Channels formed in any *in situ* paving are extra only, and the stop ends, outlets, etc., are numbered.

Raking and circular cutting to tile, brick, or marble pavings is measured by the foot run, as "cutting and waste"; and to York or other stone is given as "sunk, jointed edge, and waste," or "circular jointed edge and waste."

Reinforced Concrete. This is kept separate, in a bill of its own, and not spread over the ordinary bills of concretor, carpenter, and founder and smith.

The work is divided into—

1. Foundations.
2. Struts, columns, or piers.
3. Walls.
4. Beams.
5. Slabs, floors, or roofs.
6. Curved work.
7. Staircases.
8. Pre-cast work.

These and the various floors, working from a common datum level, are kept separate, and the heights above the datum are given.

Vertical, horizontal, and sloping, splayed and work circular on plan are further divisions.

STEEL. The steel is separated into bars exceeding $\frac{5}{8}$ in. diameter; below $\frac{5}{8}$ in. diameter, each size is kept separate; lengths over 30 ft. long; straight; bent and special bars and meshwork; stirrups; links; helical hooping, etc.

The binding wire and labour to bends is included in the description, except where high carbon steel is used, when bends, etc., are numbered as "forged bends."

No allowance is made for rolling margin in calculating the weights.

Sheet reinforcement, or fabric, is taken by the foot super, the net dimension.

A linear dimension is taken for all "raking," or "circular cutting and waste."

FORMWORK is measured the net surface of the concrete, except at angles of beams and columns, when the amount required as "passing" is included. The labour in connection with the erection and striking, and the necessary strutting, is included in the description.

For flat surfaces, as floors, the distance from the nearest support must be mentioned.

No deduction is made for the steel, nor for bull-nose, or chamfered, angles of less radius or width than 3 in.

Mention is made of the average size of footings, and if the formwork is in pits or trenches.

Pillars and beams are measured as cubic dimensions, section and shape being stated; and when over 18 ft. long, kept separate; the description must also state whether the edges are chamfered, or moulded. They are kept separate in sectional areas of—

Not exceeding 36 in.
Exceeding 36 in., but not exceeding 72 in.
Exceeding 72 in., but not exceeding 144 in.
Exceeding 144 in.

The formwork is measured in superficial feet.

Angle or other fillets over 2 in. wide necessary to form splay or moulded angles are measured in linear feet.

WALLS. The concrete to walls under 12 in. thick is measured in superficial yards, and the thickness stated; over this thickness it is cubed in the ordinary way.

Walls are measured between piers, and the piers, when not more than 18 in. in width on the face, are taken as for columns; but when over this width they are measured as a thick wall.

Formwork is measured to both sides of walls and given in yards.

FLOORS AND ROOFS. The concrete to floors and roofs is measured by the superficial yard, and the thickness stated in the description. Where supported by beams, the dimension for the latter commences at the under side of the floor, the floor dimension being carried right over.

A roof at a greater pitch than 15° from the horizontal has the formwork measured to both sides.

PRE-CAST WORK. Pillars and beams have the quantities for each particular type kept separate, and the formwork only measured for one of each type, which is numbered and the section and length stated; the preamble of the concrete must state the number of pillars or beams.

An item is taken for hoisting and setting, giving the number and size.

Junctions of pre-cast work when in position are numbered to include any formwork required.

For flues formed in walls the formwork is kept separate.

Concrete to mouldings and the formwork is measured by the linear foot, with description and the girth stated.

The jointing between the slabs after fixing in position is measured by the linear foot, the thickness of slab being stated.

SUNDRIES. Grooves and chases in the concrete are linear dimensions; holes, mortises, and similar items are numbered. When possible, mention if these are to be formed at the time of concreting, which will require templates, or formwork, or whether they are to be cut after concreting.

If the finished surface of the concrete has to be treated by hacking for plaster, stopping holes, etc., this is measured by the superficial yard.

No deduction is made from formwork at intersections of beams, or caps of columns and piers.

Raking, or circular cutting, is a linear dimension; notching, holes, and similar items are numbered.

FLOORS

Solid Basement, or Ground. Any additional excavation is added to the general amount. The floor dimension will be between the walls, and where this dimension overlaps one already taken for trenches an adjustment is necessary. Filling of dry soil, or broken rubble, where over 12 in. thick is cubed; under this thickness it is supered; the description includes for ramming.

Concrete under 12 in. thick is supered. Horizontal damp-proof course laid all over the floor is measured by the yard super.

The finishings may be cement render, granolithic paving, tiles, patent flooring, or wood blocks, measured by the yard super as mentioned in connection with pavings.

Wood blocks and tiles have a cement and sand screed taken. Solid floors may be covered with ordinary floor boards laid in mastic, and nailed to a thin layer of breeze concrete; the floor boards are measured by the square, and include the mastic and the breeze concrete by the yard super. Dovetail fillets, when laid in the concrete to receive the boards, are measured by the foot

run, including the tarring, or creosoting, and the setting in position; the concrete must be measured as " including packing round dovetail fillets."

Straight cutting is not measured to the floor finishings; any splay, or irregular cutting, is measured by the linear foot for " cutting and waste"; wood block floors, which have a border, have a linear dimension taken for " extra value."

EXAMPLE 6. Sheet 9 gives the method of entering the dimensions for external pavings and internal floors. It is of interest to notice that a series of dimensions is made to serve for various items, which save the " Taker's Off" time in entering, and the "Abstractor's" time in squaring dimensions.

Hollow Basement and Ground. Additional excavation, filling concrete, etc., follow the rules already given.

Hollow floors of concrete are termed *suspended floors*, and may be of reinforced concrete or R.S.J.'s encased in concrete. The rules for measurement for reinforced work have already been given. For R.S.J.'s an item is required for the formwork, or centering, to the soffits; and the concrete where of an ordinary floor thickness, that is, under 12 in., is measured by the yard super, stating thickness and that it is packed round by R.S.J.'s. These joists are booked by the linear foot, giving the size and weight ready for weighting out on abstract.

If the floor is supported by a larger R S.J., which is either partly in the concrete, or only supports the under side of the same, it is measured as the other R.S.J.'s, but will require templates under the ends, and the exposed surface will be painted.

To ends of the R.S.J.'s in the wall, numbered items for " building in ends of R.S.J.'s" are taken in stages of 6 in.

Where the lower part of the joist is encased in concrete, this is taken by the cubic foot and described, and the extra formwork measured.

Sleeper Walls of half-brick thickness, built honeycomb for ventilation, are superficial dimensions, and the description includes for labour of building in this way.

When plates next walls are carried by courses of bricks built oversailing, they are measured as a linear dimension for the material, and labour in setting the number of courses oversailing.

Damp-proof courses to sleeper walls are added to the general damp-proof course, or taken as a linear dimension, stating the width.

The different sizes of timber scantlings are kept separate, and the size mentioned in description.

The plate is measured for cubing as "fir in plates"; 6 in. extra length has to be added for halved joints and passings. The latter are taken at approximately every 20 ft. A linear dimension of " bedding plate" is taken, and if over 4½ in. wide the width is stated.

Floor joists are measured for cubing as "fir in ground floor joists."

Floor boarding is measured by the superficial yard, or square, and the description includes for the splayed heading joints and cleaning off after completion.

Air Bricks are taken as a numbered item, and included for the hole through the brickwork and rendering in cement.

Upper Floors. The plates, floor joists, boarding, and air bricks are all measured, as previously mentioned, but the joists are described as " framed."

Herringbone and solid strutting are taken as linear dimensions between the walls, and the depth of joists stated. The thicknesses of the joists are not deducted.

Sound Boarding. This is measured by the square; measure over the joists. The fillets carrying same are included in description as spiked to sides of joists. The pugging is taken by the foot super, stating the thickness, and that it is filled in between the joists.

Arches and Vaulting. Arches carried on R.S.J.'s require a skewback, and this may be in the form of concrete; it is taken by the linear foot, as also is the formwork. Measure a linear item for the labour to the skew-back or the brickwork cut to the steel. The brickwork in the arching is measured by the foot or yard super.

Vaulting is measured by the foot or yard super, stating the thickness; the labour to the groins and against ribs is measured by the foot run.

PARTITIONS

Timber in ordinary partition is cubed as "fir framed in partition," the dimension of scantling being mentioned in description.

For trussed partitions, the description will be "fir framed in trussed partitions," and the head and sill will have to be taken into the wall, and will require template and item for "ends built in," or " cut and pinned."

Straps and bolts will be measured for weighting out.

Bricks nogging is measured overall, and given

in feet or yards super; timbers are not deducted, but this is mentioned in the description.

Partitions which run the same way as the floor joist have short bearers between the joists to carry them; these are taken by the foot run as "short bearers framed between joists," stating size of scantling.

CONCRETE AND PATENT PARTITIONS are measured by the yard super, stating the thickness and, in the case of special manufacture, the name of makers.

Chases in the walls to receive the partition blocks are measured as "labour to forming chase to receive partition blocks," and the extra partition added which goes into the wall.

Partitions which are tied to the wall with iron hooks, or other ties, have these numbered with description.

The partitions, unless carried by joists, will also require bearers, taken as mentioned for timber framed partitions.

EXAMPLE 7. Sheets 10 and 11 illustrate the booking of partitions and a flat. In connection with the latter it will be noticed that an item has been "niled" and re-entered, owing to a wrong dimension being first booked.

It will be noticed that no painting has been booked in connection with the bend and Y-junction of rain-water pipe; this is because the painting has already been measured in the pipe, and this particular item is for the additional value of the fitting only.

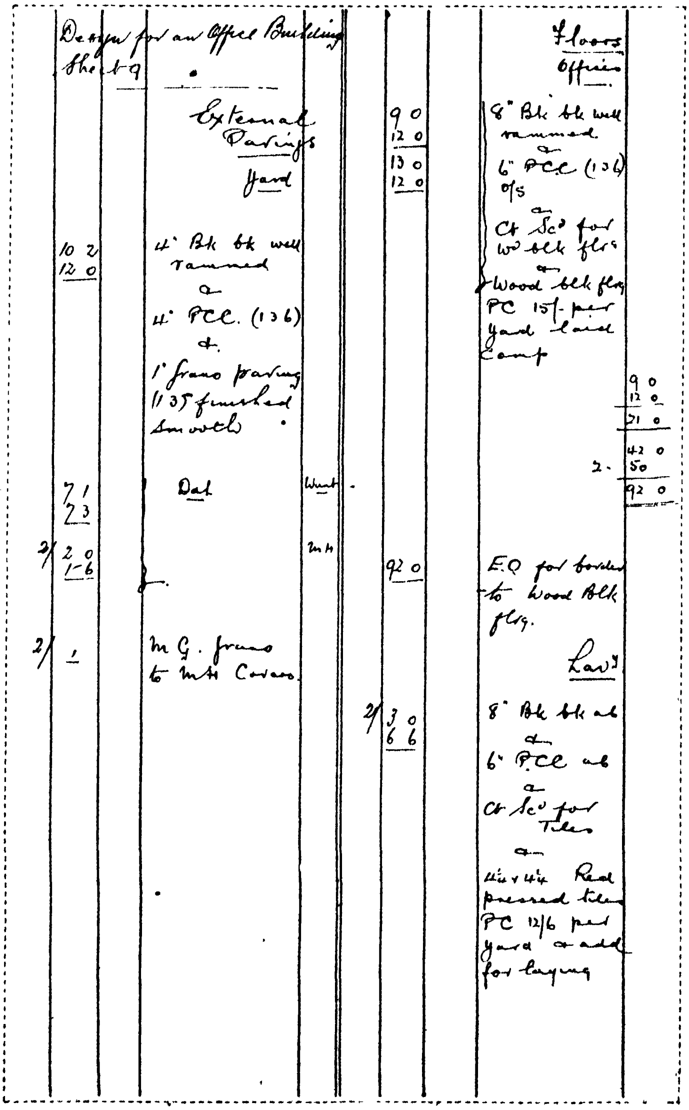
ROOFS

Flats. The work in connection with these, such as plates, joists, and boarding, or, in the case of concrete flats, the concrete, formwork, and steel, follow the ordinary methods for floors, except that the boarding where taken for a lead flat is described as "traversed for lead," and should be described as "including firrings to falls," but if the average depth of the firring is over 2 in. the firring is measured by the foot run and the average depth stated.

Asphalt on boarding has felt measured to receive same.

Drips. The drips are measured by the foot run, unless under 24 in. long, when they are numbered; the height is stated as 2 in. "cross rebated drips."

Wood Rolls are measured by the foot run, giving the size, and mitres or fitted ends are numbered; the rolls are taken not more than 2 ft. 8 in. centres for lead, and 2 ft. 11 in. for zinc.



TAKING OFF, EXAMPLE 6

Covering. The lead to flats is measured for weighting out; the actual quantity of lead required is measured, and the dimensions are booked by the weight per foot super.

Design for an Office Building
Sheet 10.

			Partitions
			12 0 − 2 9 9 3
			in wall + 6 9 9
	9 9 9 0		4½" Br Partn Slabs set in Ct
2/	9 0		Lab. cutting & bonding to bk wk.
			W.C.
	6 6 7 2		H.B wall in Ct. m.

			Flat over W.C. 6 4½ 6 6 9 9 4½ 4½ 7 6 7 7½
	7 6 7 8		4" PCC (1:2:4) in flat, pckd round mesh fabric 7' 6" off ground & B.R.C. No 13 fabric
	14 5		Chase in wall 4½" deep for 4" PCC inc cut & pin edge of PCC
2/	3 0 6 6		1½" Formwork to Soff of PCC & Hack PCC for plas
	7 6 7 8	Ded	¾" Asp in flat in two layers by app'd firm
	7 2 7 4		

Design for an Office Building
Sheet 11

			7 2 7 4 14 6
	14 6		6" Asp Skirtg inc L fillet & turning 1" into wall & R & P to last & Ro L on asp dressed into gutter
	1		m to skts & Ro L on hos
			6 4½ 9 6 6 9 14 4½
	14 5		4" C I Ogee Gutter on & inc W.I. bkts let into PCC & (3)
	1		E.O angle
	1		Stop end & Stop end Out

	2 0		3" C I R W P. & (3)
	1		E O Bend & 3" y june

Taking Off. Example 7

Zinc or *Copper* is measured by the super foot. These dimensions are taken as the net sizes, with no allowance for waste; and instead of the weight being given in pounds, it is given in zinc gauge, or Imperial wire gauge, respectively.

A bay in zinc requiring a sheet over 7 ft. 6 in. long, has the sheet kept separate.

Copper of 19 oz. weight, or over, has the "labours" kept separate.

The first dimensions are the overall sizes of the flat, to which are added the following allowances: for a 2 in. drip in lead, and a $2\frac{1}{2}$ in. drip in zinc, add 6 in. by the length; for a 2 in. roll in lead add 9 in., in zinc 6 in., and in copper 5 in., by the length of the roll.

Where lead, zinc, or copper turns up against brickwork, add 6 in.; and where a sloping roof meets the flat, the width taken under the roof covering should be sufficient to reach a vertical height of 6 in. above the flat.

Flashings. Flashings are generally taken as 6 in. wide; and the net length of the flashings is measured for lead, or oak, wedging, and also for raking and pointing to flashings.

To a net length of flashings must be added the "passings"; these are 4 in. for every 7 ft. measured in the case of lead and zinc, and 3 in. for every 3 ft. of copper.

Lead tacks, or tingles, are measured to lead flashings, and are 2 in. longer than the width of the flashing and about 2 in. wide; they are taken one to every 3 ft.

Copper clips are measured to rolls in copper flats as 6 in. by 2 in., and taken at every 2 ft. 6 in.

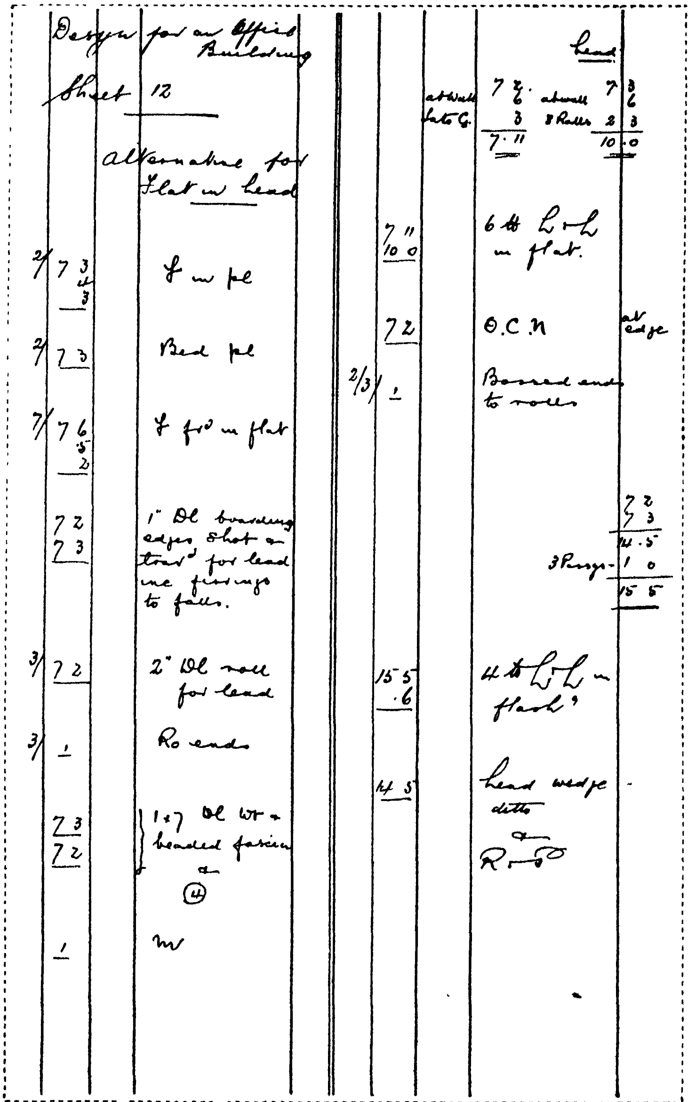
Holding-down clips in zinc are spaced every 4 ft. along length of roll.

The labour to the following is numbered: or lead, bossed ends, angles, and intersections to rolls, bossed angles to the lead flat; for zinc and copper, capped ends and saddles to rolls.

Copper Nailing. Copper nailing is measured by the linear foot, and is described as "open" when the tacks are more than $1\frac{1}{2}$ in. apart, and "close" where $1\frac{1}{2}$ in. or less.

Edges bedded in white lead are taken as a linear dimension.

Linear dimensions are measured in connection with lead and copper for the following: labour to secret gutter, ornamental work, and



TAKING-OFF, EXAMPLE 8

dressing over glass and mouldings and into hollows.

Cesspools are numbered as "extra labour," and the lead or copper is measured. Soldered angle is a linear dimension.

Where the water is taken direct through the

wall, the lead is measured in with the flat, but a numbered item is taken for the extra labour, and for dressing into the rainwater head.

Lead Pipes. Where the water is carried through the wall, the lead pipes are measured by the foot run, stating the internal diameter and substance of the lead; the bends are numbered

The joint to sole of lead gutter, or asphalt flat, is numbered.

Any tack, or other fixing, is numbered and described. The holes through walls, boarding, concrete, etc., are numbered.

Asphalt is measured by the yard super; the description states the thickness and whether to be laid in two layers, also the height of flat above datum.

Skirting is a linear dimension, the height in inches, the angle fillet, and turning into the groove being included; the amount of this " turn in " is mentioned. Mitres are numbered.

Rounded angle to edge of asphalt is a linear dimension.

Cesspools and outlets through walls are numbered for labour and materials, giving sizes.

The holes through the wall for outlet are numbered.

Channel, or gutter, in the asphalt is a linear dimension for " extra labour and materials," and the girth or size of channel is given.

Channels formed in the thickness of a concrete flat have a linear dimension taken for the labour, giving sizes and description.

Patent Roofing. Various forms of patent felt roofing are used, and these are measured by the yard super, any turn down at eaves, or turn up at walls, being added to the dimensions; a linear dimension for extra labour and nailing to eaves is taken; turning into groove and wedging also taken. Angles and mitres are numbered.

Skirting in this material requires a wood angle fillet to prevent an acute angle being formed; this is a linear dimension.

Rainwater pipe is measured by the foot run, the description giving the size, shape, metal, and method of fixing. Bends, offsets, and shoes are first measured in the length of pipe, and afterwards numbered for " extra value."

Chases in the brickwork are a linear dimension; holes through walls are numbered.

A numbered item for joint to stoneware drain is measured here, and at this point, that is, the foot of R.W.P., a stop is made, the drains, gullies, etc., coming under " Drains."

EXAMPLE 8. Sheet 12 shows the method of obtaining and booking the dimensions if the flat were carried out in lead work instead of concrete and asphalt.

PITCHED ROOFS

ROOF TRUSSES. Timber roof trusses are measured by the cubic foot, as "fir framed in roof trusses." Hoisting is taken as a numbered item, giving the height above datum. Where the truss is wrought it is stated in the description.

Joints are not numbered, as the description " framed " covers this work. The ironwork in the stirrups and straps, including bolts over 12 in. long, is, unless very small, weighted out and billed in hundredweights. Small bolts and coach screws are numbered.

The boring in the fir to bolts is measured as a numbered item, giving the depth of boring.

If cast-iron heads and shoes are used, they are numbered; and unless they are a stock pattern from a catalogue, the item should include for the mould

The painting on the iron straps, etc., is a linear dimension, giving the size of bolt heads; the cast-iron heads and shoes are numbered.

Steel Trusses are measured as linear dimensions, giving the sections employed, ready for weighting out; gusset plates, etc., are supered for the same purpose. The painting is taken by the linear foot when under 12 in. in girth, giving the size of section.

The hoisting and fixing is measured as a numbered item. The approximate size and weight and the height to be hoisted is stated.

Stone Templates are numbered, the finish being given in the description; bolt holes, rag bolts, and fixing are also numbered. A truss supported by a stanchion has the shoe numbered for planing.

Stanchions are taken off in a similar manner to other R.S.J.'s, as previously described, any base, or top plates, being supered for weighting out.

Roof Timbers are measured by the foot cube. The plates are booked as " fir in plates," all as before mentioned.

Ceiling joists, rafters, ridges, valleys, hips, and purlins are measured by the foot cube or foot run as " fir framed in roof," but the scantlings of various sizes are kept separate.

Any length of timber under 4 ft., or over 20 ft. long, is kept separate.

For scarfed joints measure an additional length of timber equal to twice the depth of scantling, and a numbered item of " labour to

scarf joint." When the joints are bolted, the bolts are numbered and the boring measured. These joints are taken at intervals of 20 ft.

Upper edge of ridges and hips which have the arris roughly taken off, have a linear dimension taken for "labour to rough splay."

Purlins or other timbers, having moulded or chamfered edges, have these measured by the foot run, and any stop ends numbered.

A portion which is wrought has a dimension taken for "planing on fir," but feet of rafters having a projection of 2 ft. or less, are numbered with full description, stating if cut or shaped.

Sprockets are numbered, giving full description.

Hips and Valleys. Hips covered with lead have a wood roll, which is measured by the linear foot; mitres or stop ends are numbered. The lead is taken as 18 in. wide, and the usual passings of 4 in. are allowed at every 7 ft., except to valleys, when the allowance is 6 in.; tingles are required at 3 ft. intervals.

Hips covered with ridge tiles are measured by the foot run, and the description includes the bedding and pointing; mitres, fair and stop ends are numbered, and where the dimension is a broken foot a cut is taken. The hips have the hip irons numbered, with full description, and the painting numbered.

Hip tiles are taken by the linear foot, and the description includes for cutting and waste to tiling on both sides, and where "bonnet" hip tiles are used, the bedding and pointing. Mitred hips on slated roofs are a linear dimension, and the description includes for the wide slates and bedding in oil cement. This type of hip also requires either a secret gutter or soakers.

Valleys laid with metal have "layer boards" measured the length by a width of about 12 in. each side of the valley rafter, and a small tilting fillet; the metal is taken about 6 in. longer each end than the ordinary net length of the valley.

To all hips and valleys, unless otherwise described, a linear dimension is taken on both sides for raking, cutting, and waste on the boarding, battens, felt, and roof covering. A similar dimension is taken on both sides of the ridge for "cutting and waste to top edge" in connection with the slates or tiles.

Splay cutting required on the boarding is included in the description of boarding.

Roof Coverings are taken as the length of the eaves by the length of the rafter back. Boarding, felt, battens, slates, and tiles are all measured by the square, and corrugated iron by the foot super. Measurements are net with laps allowed for in the description.

The vertical slopes of roofs and circular work are kept separate.

The description should state the kind of tiles, or slates, and the size, lap, method of fixing, nails, etc., and whether torched or bedded.

At verges, a linear dimension is taken for cutting and waste, including tile-and-half, or wide slates, as required. This includes for undercloak and pointing when specified. Square abutments are a linear dimension for cutting and waste. When on the skew, they are measured as "raking, cutting, and waste to skew abutments." The length of Soakers will be the gauge, plus lap, plus 1 in., by a width varying from 6 in. to 9 in. The fixing is taken by number. Step flashings in lead are measured for weighting out, and in zinc, or copper, by the super foot; they are from 6 in. to 12 in. wide. The allowances for passings, tacks, etc., are as before mentioned.

The width of secret gutters will vary with the width of the sole; measurement is similar to the last. A small tilting fillet is required.

Eaves to slating and tiling are measured as a linear dimension for double course to eaves, including any bedding; a splayed tilting fillet is also measured, and when over 2 in. by 1½ in., its size is stated. Fascia is a linear dimension and is fully described, mitres and fair returned ends being numbered. The painting is also booked. The soffit is measured as a linear dimension if boarding is under 9 in. wide; but if wider than this, it is taken as a superficial dimension; when plastered and under 12 in. wide, it is described as in narrow widths.

Rain-water gutter is a linear dimension. The description states the method of fixing, including any ordinary brackets.

The painting is taken as a certain number of oils before and after fixing.

The fittings, that is, angles, outlets, etc., are measured as "extra only" over the gutter, stop ends being numbered.

Valley Gutters. Where lead, zinc, or copper gutters are formed behind a parapet wall, or in the form of a box gutter between two roof slopes, the gutter boards and bearers are measured by the linear foot when under 9 in. wide, and the description states the average width; when over 9 in. wide, they are measured by the superficial foot, each bay being taken by the average width.

The sides to box gutters are taken by the linear foot when 6 in. and under in width, and the

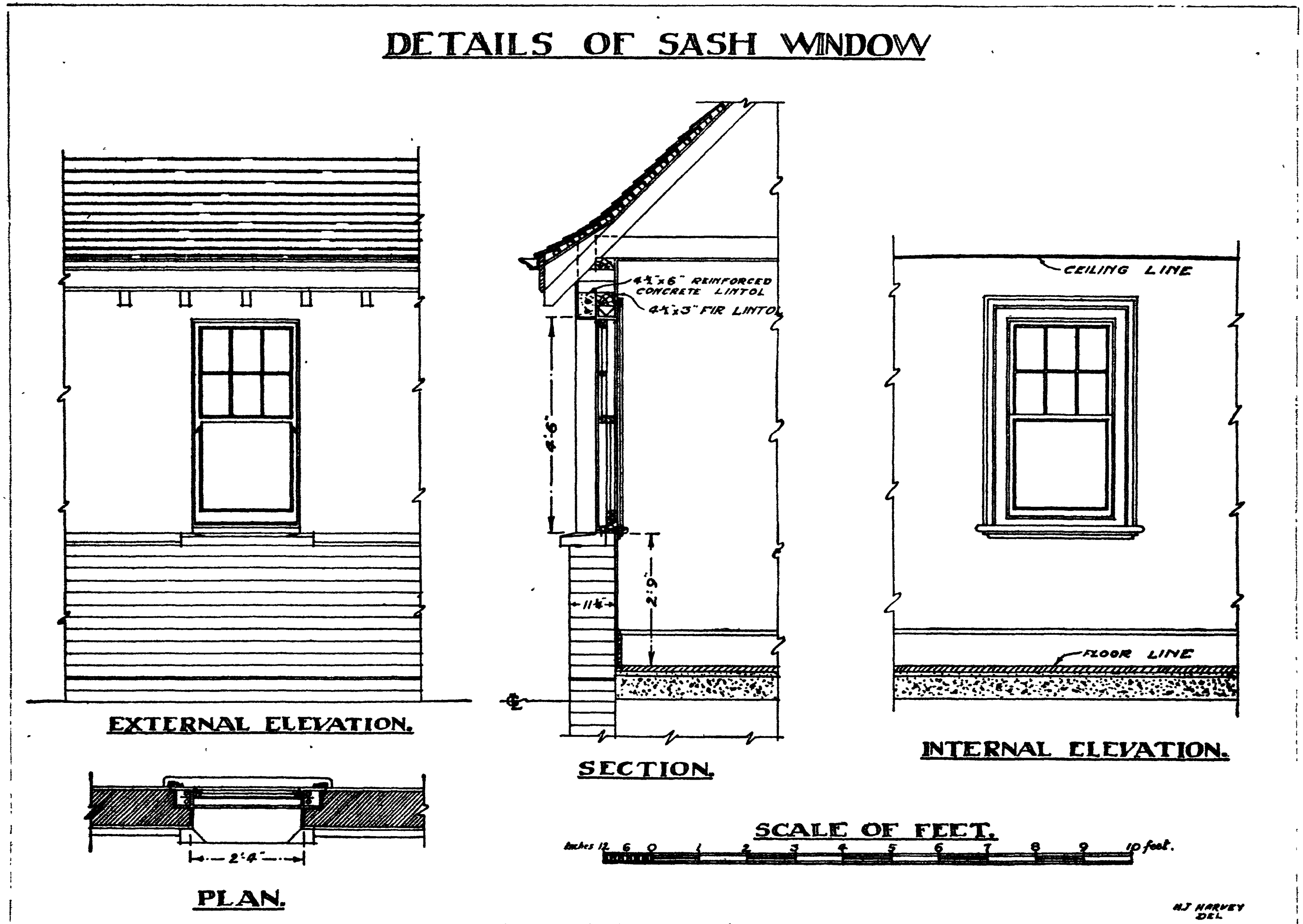


PLATE II. QUANTITY SURVEYING

superficial foot when over this width. The rolls, covering, flashing, etc., follow that of flats.

Snow boards are taken by the foot super, including bearers, and the description states the size and spacing of the battens, shape and spacing of bearers, and that they are in lengths to suit drips.

EXAMPLE 9. Sheets 13, 14, 15, and 16 give the dimensions for the complete work to the roof of the building, Fig. 2, and show the method that is usually adopted in dealing with this portion of a plan.

It will be observed that the roof has been taken off as a complete unit, and students should endeavour to follow this method in all their work.

Dormers. The roofs having been measured right through, as if no dormer existed, the first item must be the adjustment of the roof timbers. Deduct the full-length rafters which cut into the dormer, and substitute trimmers and any short rafters required; also make a deduction for roof boarding, roof covering, plastering, etc.

Framing and roof timbers will be measured and added to ordinary fir framed in roof, etc.

The windows will be measured as described later; mouldings will be by the foot run, stating size, the mitres, etc., being numbered.

The work to cheeks is kept separate as being in dormer cheeks. Solder dots are measured by number, to include the screws; the sinkings in the boarding are numbered.

Welted edge covering copper nailing requires an additional 1 in. on the lead, and a linear dimension for labour.

Tiles, or slates, covering cheeks, have a dimension for "raking, cutting, and waste" up the slope of main roof covering; measure also "cutting to top edge" under the sill, and, if necessary, an eaves course to the roof covering over.

PLASTERING

Plastering is measured by the superficial yard. A cornice over 9 in. in girth has one-half the projection deducted from the ceiling, and one-half from the wall dimensions, respectively.

Cornices less than 12 in. in girth are taken as linear dimensions, with mitres numbered. Metal lathing is measured by the foot super net, and the description must state the laps, gauge, and mesh; "raking, cutting, and waste" is a linear dimension. Angle in plastering has Keene's angle, or labour, to arris taken as a linear dimension.

Plastering under 6 in. wide is a linear dimension, but between 6 in. and 12 in. wide is supered and kept separate in narrow widths; narrow widths caused by the deduction of openings in walls, or the returns to chimney breasts, are not described as narrow, but are ordinary yard work.

Plastering reveals less than 6 in. wide are measured as "arris, or rounded, angle and narrow — in. returns," except where Keene's angle is used.

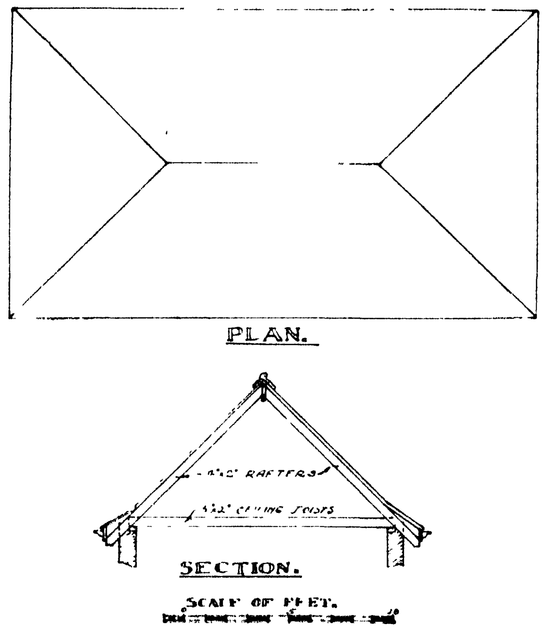


FIG. 2

No deductions are made from the plastering for an area of less than 4 ft. super.

SUNDRIES

Cat Ladders are measured by the linear foot, the description giving the size of the board and cross pieces, with distances apart of the latter. Ironwork for fixing is numbered, or measured, for weighting out.

Ways in Roof are measured in squares, but are made a "provisional item."

Ventilators, Fleches, etc. These are taken off as a unit complete under a sub-head, and include all the work measured in detail.

Conical, octagonal, or similar roofs, when slated or tiled, must have the diameter of base and apex and the height of roof given; eaves circular on plan are kept separate.

Stone, or Concrete, Stairs. If of square section, these are measured by the linear foot, with full description and the number of steps stated;

Design for an Office Building
Sheet 13.

Roof.

		10.5 / .7 / .15	add (7.15)	Ridge	
	9.0 / 4.0 / 13.0 / 22.6 / 2. 9		+ 15 C	22.6 / 16	
	23.3 / 12.0 / .9 / 35.6	18/ 12.9 / .5 / .3	4 fir in C flr (6.12)		
	Run 2. 1.0 / 73.9	2/22/13/ 1	4" sprockets spiked, out of 4x2 x 2'6" long		
		4/ 1	Ditto to hips		
73.9 / 23.9 / .3	4 in pl (6.3)				
	22.6 / 12.0 / 34.6 / 68.9	2/35/ 1	Cut to end on Rafter feet & (H) as before		
68.9	Red pl	2/25.5 / 10.9	3/4" Roof boarding & Inod. Felt & 1½ x ¾ Tile battens for tiling to a 2½ lap.		
	22.0 / 1.6 / 23.4 / 1.6 / 25.0				
	Onaling				
	Rafters @ 15" c.				
2/2/4/ 10.9 / .4 / .3	4 fir in roof (4x2)	Roof	2/25.5 / .9 / 2/15.0 / .9	Planing on boarding & (H)	Soffit of Eaves
4/ 22.9 / .3	add (7.13)	Hips			

Design for an Office Building
Sheet 14.

Roofs contd.

			2/ 1	In and fare	
					3. 50.0 / 2. 60.0 / 80.4 / 4. 1.9 / 82.6
4/2/ 12.9	RC(W) on 3/4" Boarding & Ditto on felt & Ditto on Bats				
			82.6	5" C.I. O.G. eaves gutter on bolts fixed to mushroom head bolts & (1) B/E fixing & (2) Angles	
		+ 2.	25.5 / .4 / 25.9		
		+ 2.	10.9 / .2 / 10.11		
			4/ 1	E O E	
2/ 25.9 / 10.11	10½ x 6½ Hand made S.F. roofing tiles of Broseley make, laid to a 2½" lap & nail every 5th course with two cop nails to each tile.		2/ 1	E O Ends.	
			2/ 9.9	3" C.I. R.W.P. fixed to Brick w/ R.C.	
			2/ 1	E.O 3x2 Offsets & E.O Shoes	
2/ 25.9 / 2/ 15.4	D.C tiling at Eaves.		1	E O 3x3 plinth head	
2/ 25.3 / 2/ 15.0	1x9 Bd. Wt ... (H) & Fir tilting fillet		4/ 13.0	P.M. ... Bonnet hip tiles inc. C & W on Tiling ... LM	
			2/ 10.5	Cutting to top edge on Tiling	

Design for an Office Building
Sheet 15

Roofs contd.

			2.8 / 2.10	Ddt Roof Bdg. & Felt & Tile Bats & Tiles	
10.5	Red S.F. Roll ... Tiles set ...				
			2.8	D.C E & Felt. & Top edge	
2/ 1	PM ...				
1	Cut				
	Chy ...		2/ 2.10	Cutting to ...	
2/ 10.9 / .2	Ddt 4 fir in roof (4x2)		2/ 2/ .6 / .8	...	Soakers
2/ 10.9 / .4 / .3	Add ditto (4x3)		2/ 2/ 1	F.O Soakers	
		2.8 / 3.2			+ 2.8 / 3.2 / 6 / 9 / 1.9
2/ 3.2 / .4 / .3			3.2 / 1.9	6 lb ... Gutters.	
2/ 2.6 / .4 / .3	Ddt. (4x3)		3.4 / .6 / 3.2 / 1.0	4 lb ... Flashgs	Aprons
1	... Chy ...		2/ 3.6 / 1.0	Ditto but Stepped.	

Design for an Office Building
Sheet 16.

Roofs contd.

2/ 2.10	Lead wedging & R & P ... flash
2/ 2.8	Lead wedge & R & Pointing Flashings
	Leave all roofs clean & W. T. on Comp.

(T.8463)

Taking Off, Example 9

spandrel section and all winders and landings are taken by number, stating the length and extreme dimensions, and whether of square or spandrel shape.

Spandrel steps in stone, if two are cut out of one stone, must have this stated. Where square wall holds are required, this must be stated.

Stone steps over 6 ft. long are kept separate and the length stated.

Labours to rebates, moulded nosings, moulded soffits, grooved treads, etc., are measured separately, stops and mitres being numbered.

Winders are kept separate and the overall dimensions given. Numbered items are taken for hoisting and building-in, and also for building the brickwork in sand to receive the ends of steps.

Pre-cast Concrete has the reinforcing rods included in the description.

Landings are measured as a numbered item, giving thickness and general description.

Mouldings, fair edges, joggle joints, etc., are all taken out separately.

Chases in wall for landings are taken as a linear dimension; the brickwork is not deducted; and an item is taken for the edge cut and pinned.

Staircases cast *in situ* have the steps and strings measured as a cubic dimension, giving sizes and finish.

Landings and winders are measured in superficial feet, the description giving the finish of the surface. The finish to the edges of landings is taken in linear feet, stating thickness; the ends of steps are numbered, giving sizes and shape.

Stops, mitres, etc., are numbered for the labour.

Special nosings, mouldings, grooves, chases, and rounded angles are measured as linear dimensions.

Handrails fixed to walls, whether of wood or iron, are taken as a linear dimension, with full description, the ends being numbered.

Joints in wood handrails are numbered to include handrail screws.

Brackets are numbered, with description and including cut and pinned to brickwork. Painting, staining, etc., are by the foot run.

Iron balusters and handrails of plain iron are measured for weighting out, the description stating that it is in handrails and balusters; all ramps, scrolls, and similar work are numbered for extra labour.

If of cast iron, balusters and handrails are numbered, the description giving details of design and an item for the mould for casting being taken.

Balusters selected from a catalogue should have the number quoted.

Take a groove in wood handrail for the iron core.

Take painting on plain balusters by the foot run, stating size; on ornamental cast railing, measure both sides by the yard super, overall, and state that it is measured both sides.

Ceiling and Wall Finishings

Ceiling and wall finishings are measured by the yard super.

Wood lintels and similar work require counter lathing, which is measured by the superficial foot.

The description includes for oak or fir laths, but metal lathing is kept separate, the description of the plastering stating that it is on metal lathing elsewhere measured.

Detached plastering not exceeding 1 yd. super is kept separate, as in small quantities.

The finish to fibrous plaster slabs is mentioned in the description.

Coffered ceilings and panelled walls and the surfaces, 36 ft. or under in area, between beams, or mouldings, are described as in panels, but if divided into panels by small ribs, or mouldings, are measured overall and described; the mouldings, enrichments, etc., are taken by the linear foot, with all stops, mitres, etc., numbered.

Lengths of moulding less than 12 in. long are kept separate as in short lengths.

The methods mentioned in connection with dormers also apply generally.

Ceiling beams are girthed for measurement and kept separate. When the soffit of the beam is panelled, or is under 12 in. in girth, it is stated in the description.

All mouldings and plinths and eaves under 12 in. girth are taken by the linear foot; over this girth, they are supered by the girth, and if on bracketing this is mentioned. The description for all solid mouldings should include for "dubbing out" as required.

A flat or weathered top to a cornice or plinth, less than 6 in. wide, is included with the moulding, but over this width and under 12 in. is a separate dimension in narrow widths.

For mouldings of fibrous plaster the net length and girth are measured.

Arrises, quirks, rounded angles, skirting, grooves, etc., are measured by the linear foot, and the mitres and fair ends are numbered.

Chapter III—TAKING OFF: JOINERY AND FINISHINGS

Openings, or Recesses, without joinery are dealt with first. Deduct material of which the wall is built, and also plaster and finish; the net size of the opening is measured, in a similar manner to the original booking.

THE LINTEL or arch over is next taken. But a lintel under 3 in. thick has no deduction made from the wall; if the lintel is of timber, it is measured for cubing as "fir in lintel." Unless otherwise specified, a bearing of 4½ in. each end is taken. Rough relieving arches are numbered items for "extra over common brickwork for rough relieving arch 3 ft. 9 in. span, in two half-brick rings, in one brick wall, including all rough cutting," the span of the arch being measured from ends of lintel.

Concrete Lintels are measured by the linear foot, stating the width of soffit and the height. The formwork is included in the description; mention also whether the faces are to have a smooth finish, or are to be left rough for plastering; the number of lintels contained in the dimension is stated.

Reinforcement included in description.

Arches over the opening to a wall that has to be plastered are "rough axed," and are a numbered item as "extra over common brickwork."

Rough cutting is measured as "rough skewback cutting" and "rough circular cutting," both of these being superficial dimensions.

A centre, or "turning piece," to a soffit 9 in. or less in width, is taken the net width of opening as "feet run turning-piece to rough-axed arch with 4½ in. soffit." A soffit over 12 in. and of span 6 ft., or under, is supered as a centre; but if span is greater than 6 ft. the centre is numbered, giving full description as to span and width of soffit.

For a fair axed or a rubbed arch, the first dimension is for the deduction of ordinary face work and the addition of the arch; this is measured the average length between the soffit and extrados of the arch by the height. The soffit is also measured for facing.

Circular and skewback cutting for both of these is "fair," but if width of the soffit is greater than the 4½ in. allowed for fair cutting, rough cutting is also taken.

THE FLOORING in the opening is taken to match that adjoining, the dimension being the net width by thickness of wall; if a boarded floor, the description includes for short-framed bearers.

THE WALL FINISH to reveals will be the net width by height to springing, together with the work to soffits of lintels and rough arches, etc. Reveals in fair brickwork when less than 9 in. wide are measured by the linear foot, and the width stated.

If the reveal is not a multiple of a half-brick, rough cutting in linear feet is measured.

Angles in Keene's cement, and plain, rounded, or moulded angles are linear dimensions.

The mitres to rounded angles over 1 in. radius and to moulded angles are numbered.

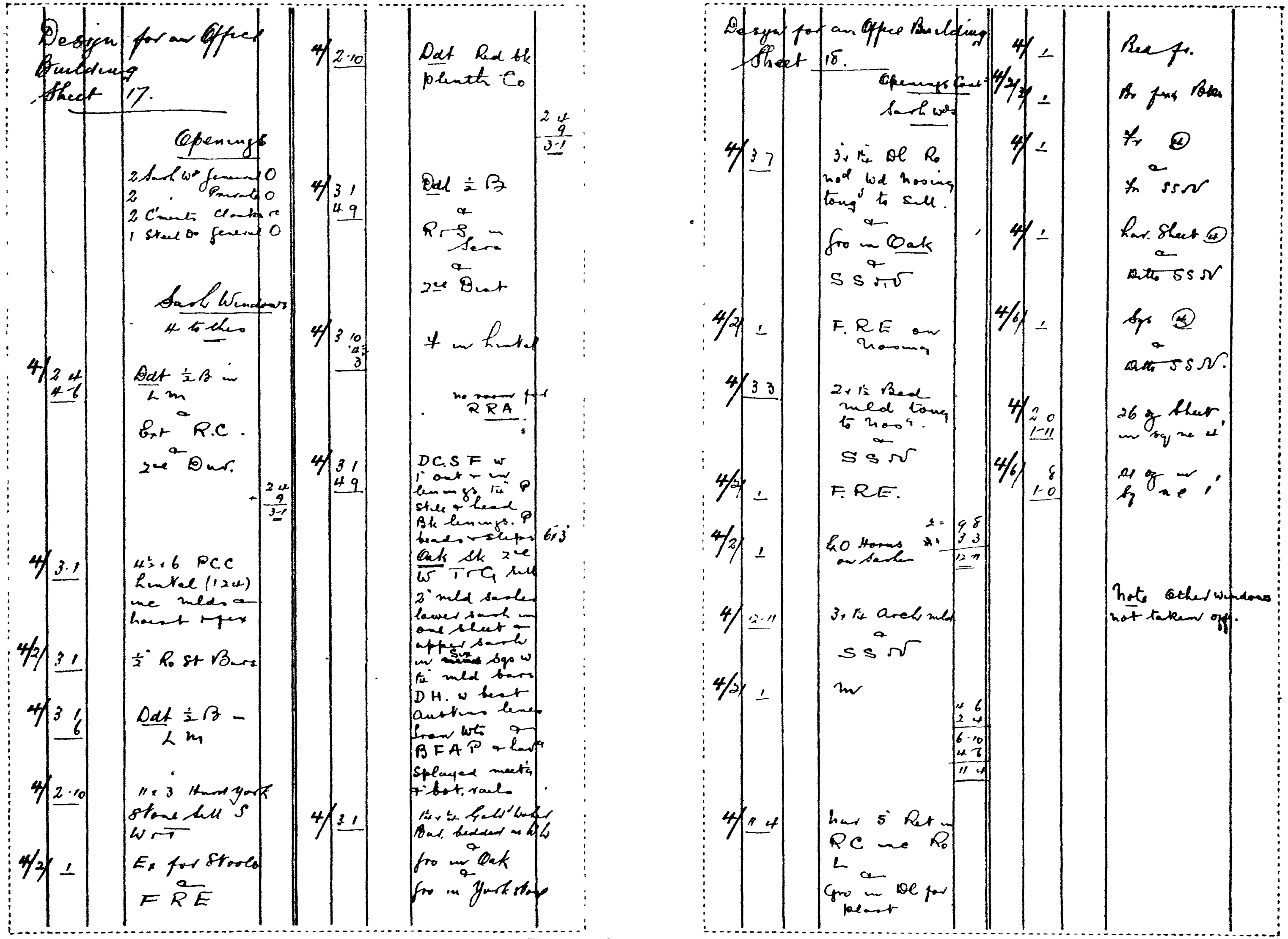
Openings in a wall with fair faces and having different bricks each side returned into reveal, have each type averaged.

WINDOWS AND BORROWED LIGHTS. Take deductions from walling as in the previous item, but with windows set in reveals the size of the deduction will vary on the inside and outside of the wall. The height is from the under side of the oak sill for the external deductions. With cased frames, 9 in. should be added to the width and 3 in. to the height of daylight sizes, to obtain the dimension of inside deduction. Arches, lintels, reveals, etc., are taken in the same way as the previous item.

Work in hollow walls requires an item for blocking up the cavity; this is a linear dimension.

Over the opening in hollow walls take a length of sheet lead, about 12 in. wide, built into the joints of brickwork, and 12 in. longer than the width of frame.

Stone window sills are measured by the linear foot, giving size and descriptions as "Ft. run 9 in. by 3 in. hard York stone, rubbed, sunk-weathered, and throated sill." If in one length, 6 ft. long or over, they are described as



TAKING OFF, EXAMPLE 10

Design for an Office Building. Sheet 20

Drainage

Give all notices & pay fees for Sewer Connection			
No. MH 2'6 Invert 2 - 2'3			
	4 0	additional Vol for Tr under paved foot path	
	6 0	Ditto Macadam Road	
			14 0 3 6 4 9 12 0 34 3
Head of Dr 2 0 MH 2 6 4 6 2 3	34 3	6" PCC (1:3:6) 18" wide under Dr pipes & benching half up pipe	
			8 0 8 0 6 0 12 0 4 0 4 0 42 0
Exc for trench Dr. ave depth 2'3" inc filling in & ramming & W & CA Surp & all P & S req'			
Ditto but ave depth 2'8"	42 0	4" SW Dr pipes jtd in Ct	
No 2 MH 3 9 Invert 3 9 6 6 3 3	4/ 1	EO Bends	
	1	Hole thro found for B wall for 4" Dr P & MG & Ditto in PCC & Tile flr an MG.	
Ditto but ditto 3' 3"			

Design for an Office Building. Sheet 21

Drains Contd

	1	6" SW gulley w Blk iron grating set on & inc blk of PCC 1 6 × 1 6 × 1 6 & inc jt to Dr	
	12 0	4" LCC Coated CI Soil P fixd to Bkwk	
	1	jt to Dr & Galv Wire Dome	
		The following in two Manholes 2.0 × 1·9 in clear	
			2 0 2 3 4 3
		2 —	
		+ PCC	2 1 6 2 7
2/	2·9 2 6 2 8	Exc W & CA	
2/	1	RF & R small portion around	

2/	2 9 2 6	6" PCC	2 9 1·9 4·6 9 0
2/	9 0 2 2	1½B in Ct	
2/	2 0 1·9	B & R in fine PCC ave 9" thick	
2/	7 6 1·5	Render in Ct & S.	
2/	2 0	Ex Lab for one Bk to bnch ops..	
2/	1	24 × 18 CI Coated MH Cover for weighing 1C & set in Ct & ft w Cart frame	
2/	1	Bkwk cut & fitted to dr pipes.	
	1	24" length of 4" Bo gld Half Sect Chan bedded in Ct & Ditto chan bend	

Design for an Office Building. Sheet 22

Drains Contd

2/	1	4" Bo Gld ¾ Sec Chan bends Ex ½ Lab H	
	1	Galv FA.I. w Brs parts & jt to Sw	
		Test Drains	

TAKING OFF, EXAMPLE 12

in scantling lengths. Stools for jambs, mitres, and returned ends are numbered. Groove for water bar is taken as linear dimension.

Take for ends of sills "cut and pinned to brickwork," and "ends made good to facings."

Openings Having Stone Dressings have the latter measured in detail for stone including labours, deducting from the brickwork for the portion of the stone in the wall. A dimension is taken for fair straight cutting on the brickwork at the vertical joint between the brickwork and the stone.

Dressings in a different brick, or gauged, brickwork are measured similar to gauged arches.

Chamfers and mouldings on the edges are linear dimensions for the labour, numbering the mitres, etc. Narrow returns at edges are taken by the linear foot: that to aprons when cut to shape is kept separate to include all cutting, or this labour is taken as a numbered item.

Breeze fixing bricks and elm or deal pads and building in are numbered items.

Cased Sash Frames are measured by the superficial foot, and are fully described.

Cased sashes and frames in single frames under 12 ft. super are kept separate as numbered items.

Horns to sashes are numbered for "extra to horns."

EXAMPLE 10. Sheets 17 and 18 give examples of the methods employed for dealing with openings. In this case the sash windows only are shown, the other windows being left as practice for the student.

It will be seen that one window has first been measured and then it has been timesed in red ink, which is represented by the heavy figures.

Solid Frames are measured by the linear foot and described as "framed," hardwood being kept separate. The tenons are included, and 3 in. is added for each horn. Bull's-eye and similar lights are numbered, with full description.

Solid frames not rebated have stops measured as a linear dimension; these stops are described as "planted on," including mitres. Beads are linear dimensions as last item, but cuts and mitres are kept separate.

Wood Casements are supered, but iron or steel casements are numbered and the sizes given, keeping separate "fixed" and "hung."

Sashes, or casements, divided by bars into squares under 1 ft. super have this specially mentioned, and casements hung folding are kept separate.

Splayed Bottom and Meeting Rails are included in the description, but deep bottom rails, deep draught beads, and rebated rails are measured by the linear foot for extra value.

Splayed or rebated stiles to sashes, grooves for plaster, linings, etc., are linear dimensions for extra labour. Rebated or hooked meeting stiles are measured for extra labour and materials.

Iron water bar is a linear dimension; the same dimension will answer for groove in the oak sill; the description includes for bedding in white lead.

GLAZING. The size of the glass is calculated. Allow about 12 in. off each way for woodwork; the result is then divided by the squares. Glass is kept separate in squares not exceeding 1 ft., not exceeding 2 ft., and in multiples of 2 ft., the description stating the method of fixing and bedding. Glass is always measured the extreme size, and all fractions called the next inch.

Glass ground and embossed has this measured by the superficial foot. Lines are a linear dimension, and small ornaments are numbered. Bevelled edges are measured by the linear foot, and the width given.

Lead and copper glazing is measured by the superficial foot, except when the width is under 12 in., when it is a linear dimension with the width stated. Squares under 1 ft. each way are numbered.

The saddlebars are a linear dimension and not included in the description.

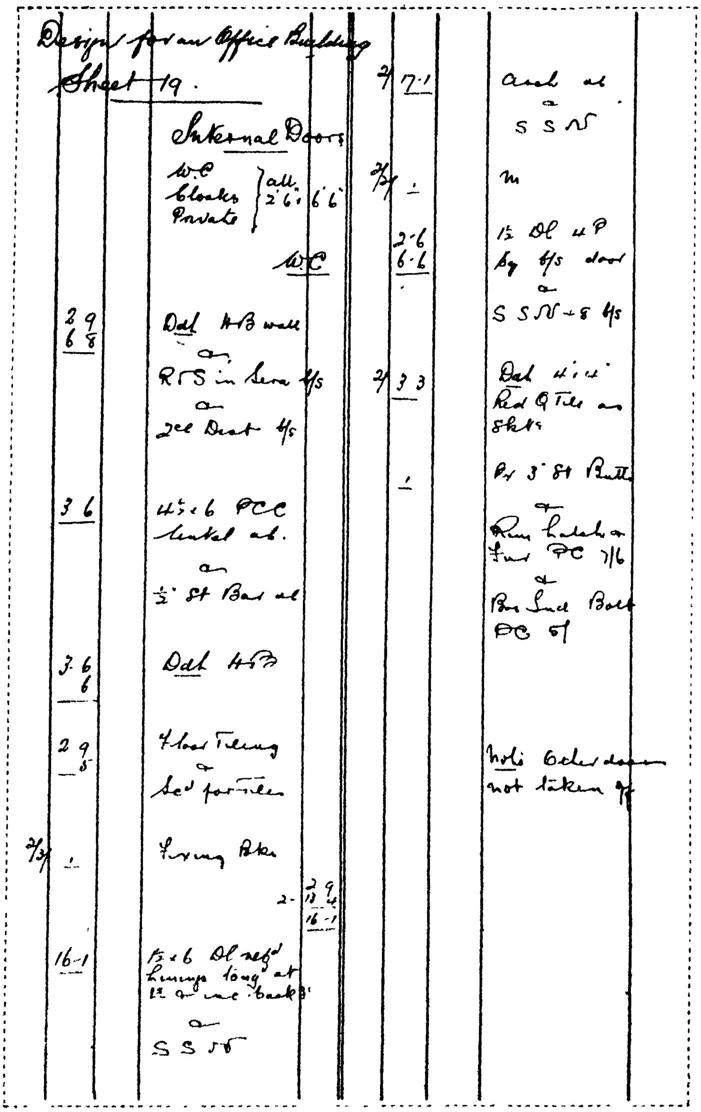
For glass fixed with glazing beads, these are measured by the linear foot, or numbered for sets, giving the size of square. Mitres are included, and if beads are fixed with brass cups and screws mention in the description. Beads under 1 ft. long are kept separate in "short lengths."

WINDOW BOARDS, also window nosing and moulding under, are linear dimensions, with sizes and the descriptions, and should include for bearers. Where the window board is tongued to the sill of sash frame, this is mentioned in the description and a dimension taken for the groove in sill. Ends notched and fitted or returned are numbered.

The linings are measured in a similar manner. Panelled linings are supered, and the number of panels stated. The description states that they are "tongued at angles"; but the ends, housed to window boards, are numbered. The description also includes for backings. The edges

to the superficial dimension are in linear feet for labours.

Window boards, or linings, over 9 in. wide are described as cross-tongued.



TAKING OFF, EXAMPLE 12

Architrave and any small mouldings are linear dimensions, with the mitred or fitted ends numbered.

Wrought or moulded grounds and rough grounds are linear dimensions, and the description states that they are "splayed for plaster."

IRONMONGERY consists of numbered items for the supply and fixing, including screws; mention whether the fixing is to soft wood or hard wood.

PAINTING, graining, or staining and varnishing is booked at the same time, and all panelled surfaces and edges are usually divided by 8, or ⅛ added.

The painting on sash frames is taken by number for each side; frames up to 24 ft. super are "ordinary"; from 24 ft. to 36 ft. are "large"; and from 36 ft. to 54 ft. are "extra large"; over this size the dimensions are given. Frames with mullion and fanlights are taken as two-light, three-light, etc., using the same dimensions; when they have a transom this is mentioned; solid frames can be booked as "lights" in sizes of multiple of 6 ft. The edges to all opening casements are numbered. These are for the frame only, and any mouldings, etc., are taken separately.

The painting to sashes is measured in squares, glass under 2 ft. 6 in. super being "ordinary"; 2 ft. 6 in. to 5 ft. "large"; and 5 ft. to 10 ft. "extra large."

Sashes glazed in one square are called "sheets," and are kept in the sizes as last mentioned.

DOORS. The instruction given for windows apply equally to doors, with the following alterations—

To arrive at the size of opening, 6 in. should be added to width and 3 in. to height of door.

Doors are measured by the superficial foot, the number of panels and the description of moulding, etc., being stated.

Each type is kept separate, and if with upper panels divided into squares for glass the number of squares is stated; doors with rebated stiles, or cover fillets over the joint, have a linear dimension taken for the labour and materials.

Swing Doors have a linear dimension measured for the labour to the rounded edges, and also for the hollow in the frame or lining.

Doors are measured the net size; the sizes of

rails and stiles are not stated unless they are 11 in. or 6 in. wide, respectively. A single door less than 12 ft. super is kept separate.

Stone steps are a linear dimension with full description similar to window sills.

Door Openings in patent, or plaster, partitions have a numbered item taken for "labour to forming door opening 3 ft. by 7 ft. in 2 in. breeze partition," or a linear dimension may be taken for the cutting.

EXAMPLE 12. Sheet 19 illustrates the work in connection with one of the internal doors, Fig. 3, and shows the work complete. The other doors, both internal and external, have been left for the student.

Trap Doors. Adjust the "fir framed" in either the floor or ceiling timbers. Traps in floors are taken as a numbered item and as extra value over the flooring. If the superficial areas are 4 ft. or less, no deduction is made from the floor boarding.

Margin is taken in feet run similar to borders to hearths.

Traps in ceilings are measured as a superficial item like doors, the linings as door linings, and any fillet, or moulding, in linear feet with the mitres numbered.

Ladders are measured up in detail as wrought and framed and kept separate ; any bolts, hooks, and other items are numbered.

SKYLIGHTS. The adjustment for trimming in rafters and ceiling joints is the same as for items already mentioned.

Roof boarding, covering plastering, etc., displaced by the skylight will be deducted, unless in the case of slating, tiling, or plastering, it does not exceed 4 ft. super, when no deduction is made.

Cutting to roof coverings, gutter boards, leadwork to gutters and flashings, soakers, etc., are taken as for chimney stacks.

Kerbs, wrought and framed, and under 9 in. wide, are measured by the linear foot, and over 9 in. by the superficial foot, the angles in both cases being numbered for the mitres.

Skylights are measured by the superficial foot, but kept separate when less than 6 ft. super in one light. All throatings are taken as a labour by the linear foot.

Rafters with glass glazed direct to them are measured by the linear foot, with description, and are described as framed.

Lead glazing strips are measured by the linear foot, and include for the fixing and dressing to glass.

Condensation gutters are a linear dimension and the outlets are numbered.

Linings are taken as for doors and windows.

Rolled, or rough cast, plate glass over 110 in. long is kept separate, but skylight glazing is always separated from ordinary.

Copper, or other, clips are numbered.

Patent glazing is measured by the superficial foot overall, and the description includes for the bars, the bearing being stated.

The painting to the skylight framing is measured overall ; that to glazing bars is taken as a linear dimension, stating the girth.

Lantern Lights follow the methods already given. The oak or other sill, angle post, mullions, and sashes are measured as described to casement frames, and the angles of sill are numbered for mitres and handrail screws. Angle posts or mullions 18 in. or less in length are separated as in short lengths.

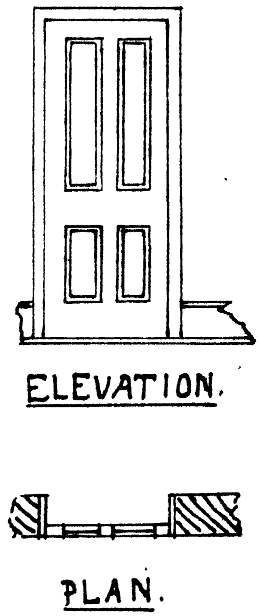


FIG. 3

Sashes, where centre hung or fixed, unless in rebated frames, have beads measured for both sides, and are described as cut and mitred. The opening sashes are numbered for opening, including the centres.

The roof is taken as described for skylights.

Ridges and hips and the hip and ridge joint between skylight framing, which is taken as a mitred joint, are linear dimensions.

Wood roll and lead covering are measured in a similar manner to work to flats, but a linear dimension is taken for labour and risk dressing lead on glass.

The opening gearing to sashes are numbered in sets, keeping the fixing separate.

STAIRCASES (IN TIMBER). Treads and risers are measured by the superficial foot ; the method of arriving at the dimension for the " fliers " is to add together the " run " and the " rise," adding 1 in. for each plain nosing and $1\frac{1}{2}$ in. for each moulded nosing. Add also to each tread

1 in. for the junction between the tread and riser. The width is the net width between the strings, plus ¾ in. or 1 in. at each end of the tread for housing into string.

Carriages. The size of the carriages is stated in the description of the treads and risers.

Housings. Each end of the treads and risers is numbered for housing to strings.

Winders. The net plan space occupied by the winders is first booked, and a further dimension booked for the varying lengths of risers, which are collected together as waste; to the net height of the risers is added the extras for nosing and joint. Winders are always described as cross-tongued. The housing of winders is kept separate for the wide and narrow ends, and also for those to newels.

Strings are a linear dimension; the various thicknesses, cut or open, ramped or wreathed, are kept separate. A short ramp, or wreath, is taken for extra value over the straight string, but the length of the ramp is stated.

The junction of a ramp with the next section of straight string is numbered for a "heading joint."

Mitres, housing to newels, framing to ends, and similar labours are numbered.

"Cut," or "open," strings having the nosing of tread returned, have this numbered, together with any bracket under.

Cappings or other mouldings, are linear dimensions, with all mitres, stop ends, housings, etc., numbered.

Rounded, or curtail, ends to bottom steps are numbered for the additional value.

Landings are superficial dimensions and described as cross-tongued. This also includes the bearers, the size and spacing of which is mentioned. Any circular or splay cutting is measured by the linear foot as labour and waste.

Nosings are a linear dimension with width and thickness stated.

Apron linings are linear, stating the width and thickness, and including backings.

Newels are linear as "framed newels"; or they may be a numbered item, when the length is stated. Extra labours, caps, drops, and similar items are numbered.

Turned newels have the length of the turning described, and a turned newel over 6 ft. long has the length stated. Mouldings planted on or let into the newel to form neckings or panels are numbered, with full description.

Handrails are linear, ramped and wreathed being kept separate; or when only in short lengths, numbered for extra value.

Mitres, housed ends, scroll, or other finishing to ends are numbered.

Handrail screws are numbered for the junction of straight and ramped, or wreathed lengths. A straight length of handrail exceeding 10 ft. has the joints and handrail screws measured.

Handrail brackets are numbered, including the fixing to wall.

Balusters are numbered and described, the length being stated. The housing at ends to strings and handrail is numbered.

Painting, etc. The strings are measured separately, as they are only measured on the exposed portion. Treads and risers are not measured for painting, unless specified, but when measured are a super dimension. The painting or polishing on balusters is taken as a linear dimension, the size being stated.

Polishing is measured by the superficial foot. Handrails, whether painted or polished, are a linear dimension, the girth being stated.

Plastering. The plastering to the soffit of stairs and landings is measured as usual for plastering, but sloping and flewing portions are kept separate.

Quirks are linear dimensions.

Spandrel framing is measured similarly to dados, the net size being taken, but is kept separate.

Skirting, picture rails, dado rails, wood cornices, etc. These and other mouldings are linear dimensions, with full description, grounds or plugging to wall being included. All mitres, returned, housed and fitted ends, and short lengths under 12 in. in length are taken by number. The painting, staining, or other finish is a linear dimension, giving the girth.

DADOS, PANELLED FRAMING, ETC., are measured by the superficial foot, except when 12 in. or under in width or height, when they are taken by the linear foot, stating the width. The description states the type of grounds, method of fixing, and the number of panels in height. A dado of match boarding is measured in squares or yards super, any capping being taken as a linear dimension.

All dados 3 ft. high or under are kept separate, and described as "dwarf."

Panels having a large bolection moulding have the size of same mentioned in the description.

Raised, moulded and mitred, or linen fold panels are numbered for extra value, and the average size stated.

Sundries to Panelling. Enrichments in mouldings, inlay, and mouldings planted on are linear for extra value.

Doors in Panelling are numbered for the extra value in forming, and the rebates and stops are all included in the item; the size of door, together with the number of panels, is stated.

Capping, cornices, etc., are linear dimensions, and the mitres, returned ends, etc., are numbered.

Painting or other finishing is taken as previously described.

Fittings. These are taken out complete and grouped under special headings in the bill.

Cupboards. Ordinary cupboards are measured similarly to dado and panelled framing.

SHELVING. Shelving in slate, or marble, 9 in. or under in width, is linear, and over this width is supered as is all deal shelving. In slate, or marble, 5 ft. or over in length, it is kept separate as "scantling," and over 8 ft. long the sizes given. Deal open-joint shelving is supered overall, but the sizes of the slats and spacing are stated.

Grooves, rebates, splays, moulded edges, etc., are linear for labour, and shaped corners, etc., are numbered.

The bearers for shelving are linear, the method of fixing being given, and the description includes for all mitres.

Gallows' brackets and steel, or iron, brackets are numbered items.

Painting on shelves is a superficial dimension, but if the edge only is painted, this is linear; the painting on the brackets, etc., is numbered.

Rails are a linear dimension, with full description as to the labours on the edges, and method of fixing to wall. Hat and coat hooks are numbered.

Dressers are taken out in detail, but are kept under a heading of their own as " the following in one dresser "; the ordinary rules for joinery apply. Legs and rails will be linear dimensions, described as " framed."

The pot board and top are superficial dimensions, stating that they are " glued-jointed and cross-tongued." Shelving is taken as ordinary shelving. The cut standards are taken in a similar manner but kept separate, and the description should state that they are in cut standards.

Doors and matchboarded back all follow the methods already mentioned.

Drawers are measured in detail, and kept under a sub-heading. The front, sides, and back, if under 9 in. in width, are linear. The angle joint is a linear dimension for " labour to dovetail joint."

Grooves, both across grain and with grain, and grooves or small beads to the shelves for plates, are linear dimensions. The ends of standards are numbered as " ends of 8 in. by 1 in. standards, tongued to dresser top."

Plate racks, where only small, are taken as a numbered item, with full description, but when of considerable size are taken in detail.

BUSINESS FITTINGS should have a heading such as: " The following in mahogany shop fittings," and then sub-heads to the various types of fittings. Care must be exercised in describing the items, as, for example, a counter top, which is a superficial dimension; it should be clearly stated whether the top is to be in one width or glued up.

SPECIAL CODE OF MEASUREMENT. Under the special "Code of Measurement of Building Work in Small Dwelling-houses" at present in force the following are taken as numbered items in lieu of the method before described, viz.—

- Casement Windows.
- Sash Windows.
- Doors.
- Cupboard Fronts and Doors.
- Plain Window and Door Linings.
- Door Frames and Frames to Metal Windows.
- Framed Skylights.
- Pantry Fittings.
- Draining Boards.
- Staircases.

Note. In connection with the latter it is considered better to give some measured details of the construction, and sizes should be given for all the other items with a complete description.

Chapter IV—TAKING OFF: DRAINAGE ETC.

Drainage

In drainage work, the method is to take each of the items of excavation, concrete, and pipes separately. These three items are linear dimensions; for the excavation, the width and the average depth are stated.

The work in excavation is described as "part returned, filled in, and rammed, small portion carted away," or whatever is the method adopted for the disposal of the surplus. The description of excavation should include for any planking and strutting required. In taking the length of pipes, remember that the ends finish on the inside of the brickwork of manholes. The description for the pipes must give full information as to the quality, how laid, and method of jointing; and the description for the concrete should state the width, thickness under the pipes, and if benched up or placed all round the pipes.

Drains. Stoneware drains are not taken in odd feet; the ordinary drain pipes are made in lengths of 2 ft., and a length of drain is measured as 36 ft., and not 35 ft.

Fittings to the drains, such as bends, junctions, diminishing pipes, etc., are taken as numbered items, for extra value over the straight pipe.

Fittings in the form of gullies, rain-water shoes, intercepting traps, etc., are numbered for their full value, together with excavation, concrete, labour in setting, and other work in connection with them, including the joint of the particular fitting to the drain.

Iron drains are taken in a similar way, except that dimensions are taken the net length; if the length is such as to require a cut length of pipe, a numbered item is taken, including the labour in cutting.

Suspended iron drains are kept separate.

An iron drain carried by iron straps has these measured for weighting out, and items taken for the cutting and pinning ends, or other method of fixing.

MANHOLES. Manholes in iron drains are numbered, and the description states the number and sizes of the various branches. With these manholes, as also all fittings, quote the catalogue number. If these manholes have brickwork this is taken as for ordinary manholes.

Brick Manholes. These should be taken out in complete detail, but kept under a sub-heading, as, "The following in four manholes,". the methods of measuring following the ordinary work, as mentioned before. The item of "benching and rendering" is a superficial one; the full size of the interior dimensions and the average thickness are stated. The channel is a linear dimension, but three-quarter section bends for the branches are taken as numbered items. The interior, whether rendered or pointed, is a superficial dimension.

Take numbered items for supplying and fixing step irons, for the supply of the manhole cover and bedding same on brickwork, and ends of drain pipe entering the manhole, including cutting the brickwork to same.

Testing. A note is made for testing drains; the method to be used should be mentioned.

EXAMPLE 12. Sheets 20, 21, and 22 give the dimensions for the drainage, Fig 4, of the building, and attention is drawn to the manholes being measured in detail, and completed under a sub-heading of their own. The heavy figures in connection with the manhole show where certain of the work has been twiced in red ink.

The attention of the student is directed to the examples of dimension sheets which have so far been given, and the taking off in connection with the various items, but to get a proper grip of the method of working it is necessary that he should "take off" some work from other plans, possibly a little more complicated than the small drawing used in this section.

In quantities, as in all other work, it is only constant practice that will make perfect; no amount of reading without practice will enable one to prepare a bill.

Cesspools. These are measured similarly to manholes. When they consist of a circular pit lined with brick, or stone, it must be remembered that the dimension for this is the mean circumference, and being "circular on plan" is separated from any straight work.

Plumbing

The various sanitary fittings are taken off as one complete unit, for example when taking off a lavatory basin the work to be measured will be: lavatory basin, trap and

joints, waste pipe, hole through wall, stack head, and pipe. The water supply with its connection is taken with the water supply.

Sanitary Fittings are entered as a p.c. sum. This sum should include—

For w.c. apparatus .	Pan and trap, waste-water pipe, brackets and seat.
For bath . .	Bath, hot and cold valves, and trap.
For lavatories .	Basin, hot and cold valves, plug and washer and brackets.
For sinks . .	Sink only, unless of a special description.

Treat other fittings in a similar manner.

After entering the item for the p.c. value, the fixing of each part is taken by number; any holes through floor, walls, etc., are numbered with the description of making good.

Lead pipe, when 4 ft. or less in length, is described as being in "short lengths," labour to bends is only measured to pipe 1½ in. and over in diameter. Short lengths of pipe in wrought iron are taken as a numbered item, with all bends and other fittings described.

When using lead pipe the weight is generally given in the preamble, under the use to which it has to be put, such as—

Service pipes, ½ in. at 6 lb. per yard.
Service pipes, ¾ in. at 8 lb. per yard.
Service pipes, 1 in. at 12 lb. per yard.

Or the weight can be stated in the description.

Solder joints on lead pipe, and the joints of wrought-iron pipe to valves and fittings, are numbered items.

Lead traps are numbered, the type of trap and weight and the solder joints being included in the description.

EXAMPLE 13. Sheet No. 23 illustrates the method of taking off the plumbing work.

It will be noticed that bends have been measured on the 1½ in. lead pipe, but not on the 1¼ in.

Soil and vent pipes are linear dimensions, and when in iron the various fittings are numbered for extra value. When in lead, the bends are numbered.

Soldered joints, brass ferrules, joints of pan to socket, or thimble, caulked or cement joints to drains, and wire balloons are numbered items, but the ordinary caulked joints on iron pipes are included in the description.

Holes through floor, walls, etc., are numbered. The hole through the roof for pipe and also the lead slate is numbered, with description.

Stay bars are measured for "weighting out," bolts, screws, and holes being numbered.

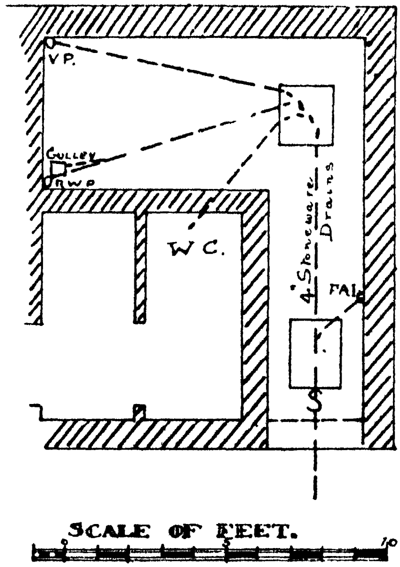


FIG. 4

Painting the pipes, stays, etc., is a linear dimension.

Water Supply. The plans, or a tracing, should be marked with the "runs" of the pipe, to enable them to be properly measured.

Take a numbered item for tapping the main, together with the payment, if any, of fees, but find out from water supply company just what they include in their fees.

Water Pipes. The weights of lead pipes are stated; when wrought iron is used, mention the kind, that is, "blue," "galvanized," or "coated with Dr. Angus Smith's solution."

Take the "rising main" first, and separate that laid in trenches and that fixed to walls, etc. The items are linear, and lead includes all "running" joints, and when 1¼ in. or under includes the bends. Over this diameter, bends are numbered. Wrought-iron pipes of a diameter of 1½ in. and under include all short running lengths, sockets, connectors, elbow bends, and fire bends, and both pipes include ordinary clips, or wall hooks, for fixing. Built-in clips are numbered.

Wrought-iron pipes larger than 1½ in. do not include in the running length for elbows, bends,

or fire bends, which are numbered items. In all cases, tees and diminishing pieces, or sockets, are numbered.

Trenches for the pipes and protection are a linear dimension, giving the width and depth. Breaking up road surface is taken for extra value. Numbered items are stop cock, pit, and cover in roadway, hole through the wall or foundation, stop cock, and draw off inside the building.

Supply cistern is a numbered item, the size in gallons and gauge of metal being given; include for hoisting and setting in position.

Bearers are measured as previously described for these items. Protection from cold in the form of sawdust, hair felt, or slag-wool packing, is taken as a superficial dimension, stating the thickness.

Boarded casing is taken in a similar manner, but kept separate, and includes the bearers, or ledges.

Lead safes under cisterns are taken as for other sheet lead work; see "Flats."

Work in connection with the cistern is now measured, the hole for supply pipe, ball valve, and fixing being mentioned; for a lead supply, take a solder joint to the union.

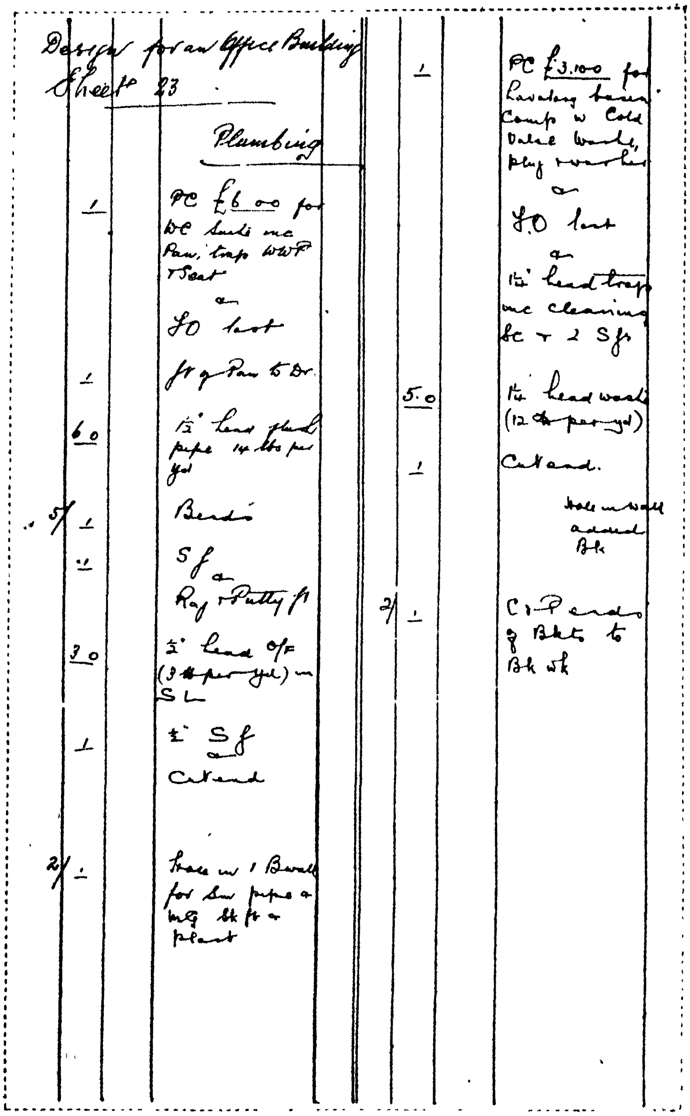
Overflow. The overflow requires a hole in the cistern, and a boiler screw when in lead, or two backnuts when in iron. A lead overflow is taken to the safe, and will have a tafted and soldered joint to the safe. Copper flaps on the external ends of overflow are numbered items.

Measure supply services next. A hole is taken in the cistern for each supply taken off, together with boiler screw and solder joint, or backnuts, as the case requires. Stop cocks are numbered items, also any holes in the cistern casing.

Supply pipes are measured as previously described, numbering the connection to fittings.

The holes through walls, floors, etc., and tees, or solder branch joints, are numbered items, stating the sizes.

Hair felt, asbestos, wood, or other casing or covers, are measured as linear dimensions. Painting on pipes is a linear dimension but unless specified this is not taken to lead pipes nor to pipes behind casings. The painting on casings will be a linear dimension when under 12 in. wide.



TAKING OFF, EXAMPLE 13

EXAMPLE 14. Sheet 24 shows the method of taking off the water supply.

Hot-water Supply. This is measured like wrought-iron pipe, but is described as "steam" pipe.

Copper piping is a linear dimension, with all the fittings numbered. The description gives

the internal diameter and the Imperial Standard Wire Gauge thickness of metal.

Keep separate the stock, purpose-made, and bends in the running length of copper pipes. Lengths 4 ft. or under are kept separate as in short lengths.

Boiler, tanks, and cylinders are numbered, and the tappings and connection to the boiler are also numbered.

Connections to tanks are as for cold water cisterns, but those for cylinders are included in the description of the cylinder.

Bearers, or cantilevers, are numbered and the ends taken as cut and pinned.

Asbestos covering to cylinders is a superficial dimension; the painting is included in the description.

At the end of water system there should be a clause for testing.

Gas-fitting. The rules given for wrought-iron water pipe apply to this. Connections to fittings, wood blocks, elbows, bushes, and fixing the fittings and incandescent burners, globes, etc., are all numbered. The chases in walls and making good same are linear dimensions.

A numbered item is taken for the supply of gas meter by the supply company and the connection by them, the description stating that any fees are to be paid.

Take also a shelf to carry the meter, as a numbered item.

An item is taken for testing the system.

Electrical Fittings

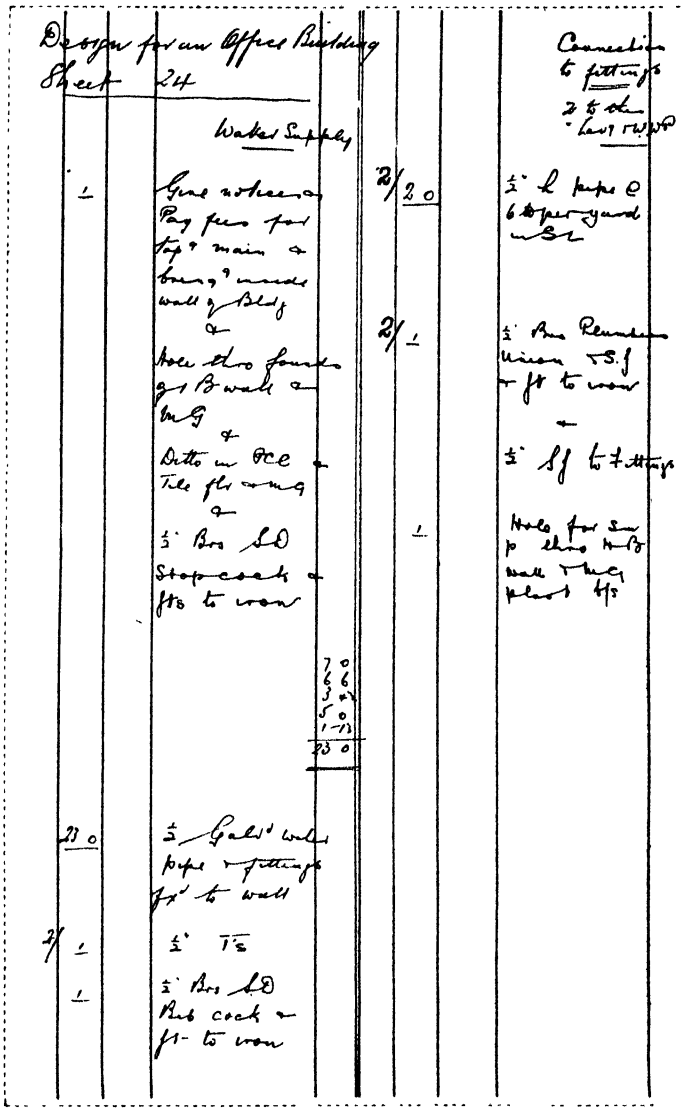
Electric Bells are taken by the number of pushes, keeping them in groups of those to ring on to an indicator, and those which ring on separate gongs.

The best method is to take the average runs of wire for those on the indicator as—

" No. —— wire with No. 20 S.W.G. double cotton and paraffin waxed wire, enclosed in slip joint steel conduit, embedded in the wall plastering, average run per point 20 yd., and to ring on indicator elsewhere taken."

" No. —— bell pushes, p.c. 3s. each, fixed to walls and include for wiring."

" No. —— ten-hole pendulum indicator enclosed in polished teak, glass-fronted case, each hole written in gold with name of room, and including best quality gong, connection of circuits, and fixing in position in kitchen."



Taking Off, Example 14

Bells ringing direct to a gong are taken off in a similar manner.

A numbered item is taken for bracket for the batteries.

Wire and Other Bells. These are taken off in a similar manner to the electric bells, but take a "bell board," upon which the bells can be fixed, as a linear dimension with full description.

With all bells a clause is added for attendance on the bell fitter.

Electric Lighting. Take an item for paying fees required for bringing the cable into the building and supplying the meter, etc.; number the private main switches, fuses, and main distribution board, running mains to any sub-distribution boards, with the average length of the run in yards, the description giving the size of conductors and the conduit; any special fittings, such as tee boxes, inspection boxes, etc., are numbered for extra value.

Sub-distribution boards and the various lighting points are numbered, with the average runs of conductors.

Switches are taken by number to include fixing.

Fittings, including ceiling roses, lengths of flexible conductor, counter weights, shades, special fittings, the supply and fixing of lamps, are numbered.

An item is included for testing to satisfy the local supply company and fire insurance company. Attendance is measured in detail.

Heating Work

Heating work is measured in full detail. Boilers are taken as a numbered item, the description giving full particulars as to size and heating capacity; where any attendance is required for building brickwork, this is measured in feet or yards super, but kept separate under a sub-heading.

Brick flues and chimney shafts are kept separate, shafts being taken in the usual heights for brickwork, with the thickness of brickwork and shape of shaft stated. The flue is deducted from this brickwork. Firebrick lining is taken in superficial feet, the bonding or connection to the ordinary brickwork being mentioned.

Cast-iron piping is a linear dimension, with the method of jointing mentioned. Fittings are numbered for extra value.

Wrought-iron pipe is measured as described for water piping.

Radiators are measured by the superficial foot of heating surface, the description giving the kind of radiator required.

All valves, cocks, and brackets and stays for piping, or radiators, are taken as numbered items.

Painting on pipes is a linear dimension; on radiators, superficial; and on brackets and similar small items, numbered.

The attendance on heating engineer is measured in detail.

Sleeve pieces to the holes through walls, etc., and thimbles and hinged floor plates to radiator piping through floors, are numbered items.

Sundries

Fencing is measured out in detail, excavation and concrete to post holes being cubed, but kept separate, unless the holes are of small size, when they are numbered. The posts and fixing are numbered. Rails, capping, gravel-boards, etc., are linear dimensions, the boarding is supered, and mortises for rails, etc., are numbered.

Gates are measured like doors.

Staining, tarring, etc., are superficial dimensions.

Cleft chestnut fencing is taken by the linear yard, with full description, the posts and gates being numbered.

Cast-iron railing is measured by the linear foot, with description and catalogue number; mention how fixed, number the gates, and take the painting as a superficial dimension, either one or both sides.

Wrought-iron fencing is measured for weighting out.

Variation of Methods

In this treatise the general rules for the preparation of a bill of quantities based on the Standard Method of Measurement have been given, but it is of great importance that a student should realize that every plan must be judged on its own merits, and that occasionally items have to be measured in a way that would appear contrary to the rules. For this reason it is also important that the student should have a thorough knowledge of building construction, and be able to act on his own initiative. Every plan which is received is different from another and must often be approached in a different manner, and it is up to the quantity surveyor to judge for himself the best manner of approach.

Chapter V—ABSTRACTING AND BILLING

Abstracting

Abstracting is one of the first things upon which the student works, but is the second operation in the preparation of bills of quantities.

With the completion of taking off, the dimensions are now squared and abstracted, in preparation for "billing."

The dimensions are first "squared," entering the results in the third column of the dimension paper. This is done in black ink. These are now checked and the correct items ticked, or errors altered, which is carried out in red ink.

The dimensions are now ready for abstracting.

Example 15. The example shows a sheet of dimensions which have been squared and abstracted. It will be seen that the squaring has been ticked in red ink; where a mistake has been made, it is corrected in red, and afterwards checked in black, which is represented by the light ticks. The method of cutting through the items will be seen; the first, the light line, represents the black ink, and the heavy line represents the checking in red ink.

Abstract paper is similar to that shown in Example 16. The name of the job, the name of the trade, and any sundry information, is first written at the head of the sheet as shown.

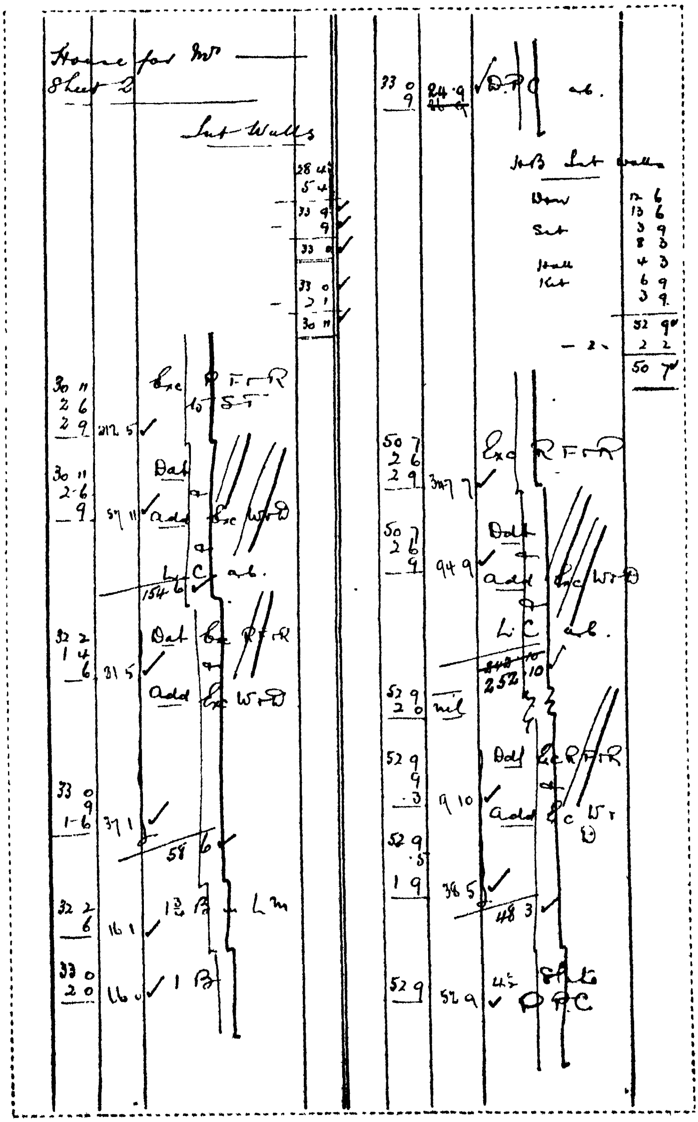
The abstracts are read down the columns, and not across the paper, and represent the final order in which the bills will be written.

Several sheets are now headed with the names of the different "trades," and a start is made with the first dimension on the dimension sheet. The abstracting is carried straight on, taking each item as it is booked, and not abstracting trade by trade as some people suggest.

Each item abstracted is cut out in black ink over the description.

When there is a series of dimensions of the same description, it is not usual to abstract each one; they are added together and only the total taken to the abstracts. All deductions are not abstracted; where a deduction follows an addition, the adjustment can be made on the dimension sheet.

Put the totals of these figures in the description column, to avoid adding them into the dimension figures.

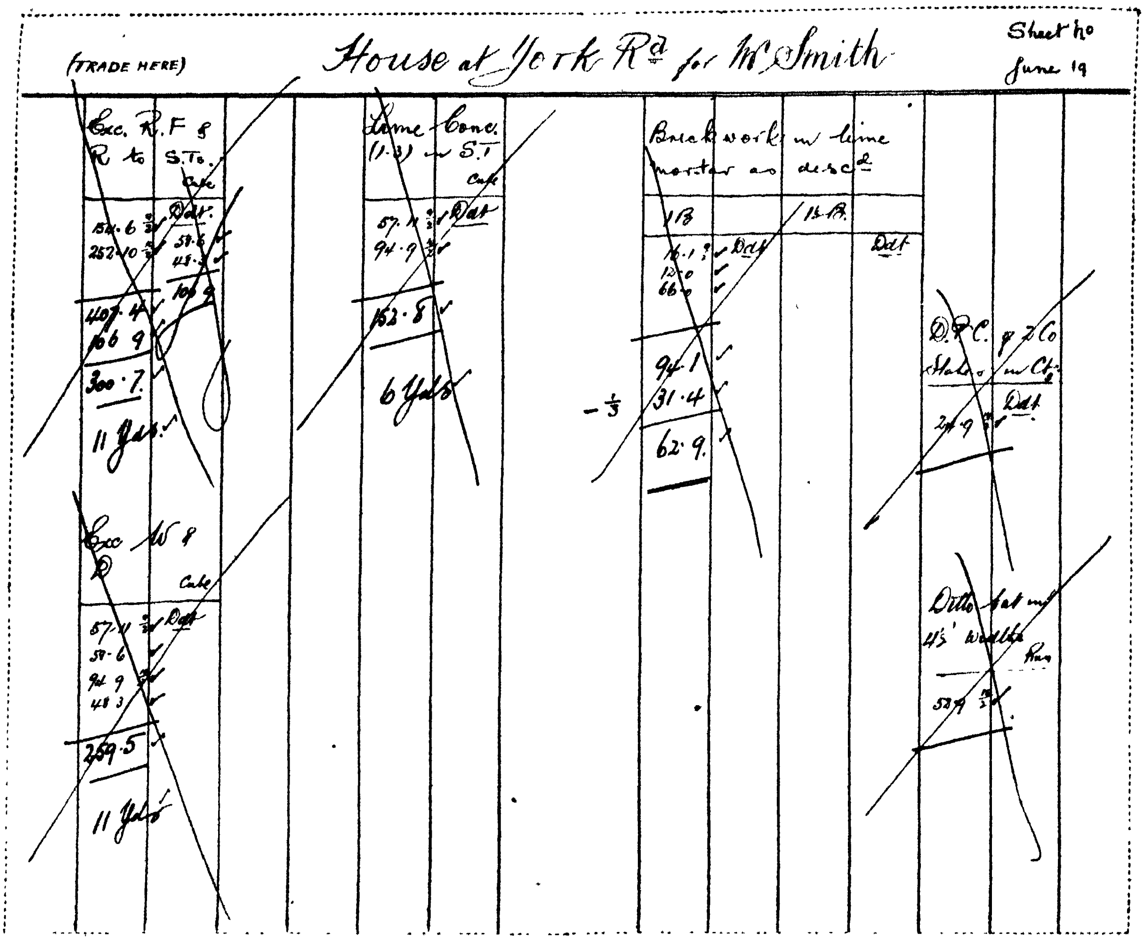


Taking Off, Example 15

A dimension standing for two or more items has each description, except the last, cut through with a sloping line, and the vertical line is made after the last item has been abstracted.

Each page of dimensions on being abstracted is looked through to see that everything has possible query; if an alteration has been made, it is very desirable that this should be referenced.

The method is to write the sheet number and column, or page number, of dimensions against the items.



ABSTRACTING, EXAMPLE 16

been cleared, and, if so, a tick is placed in the lower right-hand corner; and when checking, the same is done in red ink.

The abstract when completed is checked.

The items on the abstract are ticked in red, and those on the "dims" cut through in red. When an alteration has to be made, do not alter the figures, cut them right out in red, and re-enter in the same ink.

Items are sometimes referenced; this may only be the first one, but can be any item having a

Do not crowd the paper; allow plenty of room for every item. A crowded abstract leads to errors. Make clear figures and keep them in straight lines.

Having checked the abstract, it is *reduced*, which is carried out in red ink. The columns are first cast and then reduced to the various standards, and checked in black ink.

Deductions made on the abstract, or any item transferred to another part of the sheet, are cut through with a loop, as shown.

The general order for abstracting is cubes, supers, linears, and numbers, and of these items the cheapest in price and smaller in size is placed first.

The amounts in excavator and concretor are brought to yards super by dividing by nine, and to cube by dividing by twenty-seven. Surface excavation is placed before cube excavation; but broken brick and stone over site, surface concrete, and similar items are more expensive than bulk work, and will follow the general rule of cubes and supers.

In abstracting brickwork, only three headings are required: one brick, one-and-a-half brick, and cube, with their deductions.

To abstract 3B, take twice the dimensions to 1½B column; to abstract 2½B, take the dimension to both 1B and 1½B column; and so on.

In reducing, transfer all brickwork to the 1½B column; to do this, deduct one-third from the total of the 1B column; and from the cubic column, one-ninth. The results are 1½B. The final total of 1½B is divided by 272, which gives the result in rods and feet of reduced work.

For the Midlands and the North, work, except where it is over 3½B thick, is reduced to the yard super one brick thick; over 3½B thickness, it is given in cube yards.

Half-brick walls are kept separate, except when taken as an additional ½B thickness, when they belong to the general brickwork, and half, or one-third, the dimension is entered under either the 1B or 1½B respectively.

With facings, keep them under sub-headings, and after the whole of common work has been dealt with.

The first item in carpenter is centering, which is a cheap item, but not a cubic one.

After centering, comes bracketing to joists, cornices, etc., and then the cubes for plates, lintels, and so on.

Floors are the first joiner's items, starting with the cheapest kind. In this trade use plenty of sub-heads: windows, doors, finishings, hardwood, and similar woods, and also other different woods.

Separate fixing ironmongery to soft woods and hard woods.

Subdivide cast iron, wrought iron, and steel in smith and founder.

Separate R.S.J.'s under 5 ft., or over 30 ft. long, the latter in groups of 5 ft.

Holes in web and flange and those drilled on site and in position are kept separate.

Separate "internal" and "external" plumbing, and use plenty of headings, as "water service," "soil pipes," etc.

Lead is billed in "cwt.," zinc as feet super "zinc gauge," and copper as feet super "I.S.W.G."

Glass is kept in squares of not exceeding 1 ft., 2 ft., 4 ft., and so on, advancing by 2 ft.; if over 54 in. long the glass is separated.

Polished plate has squares 9 in. to 18 in. wide, and 45 in. or more long, and also those over 36 in. each way, kept separate.

Painting is grouped as "on steel," "on iron," "knot, prime, stop, and three oils on wood," and so on; and under these headings the proper work is collected.

All plain yard work is described as "general surfaces."

The wallpapers are booked by the piece, and the dimensions are abstracted in superficial feet. To reduce to pieces of paper, divide this amount by 54, which gives the number of pieces of English paper, including allowance for waste. Waste is not taken to lining paper; divide by 60 to obtain the number of pieces.

EXAMPLE 16. This example shows an abstract of the items on the dimension sheet in Example 15, and it will be seen that the items have been checked in red ink and reduced in red ink, afterwards being checked in black ink. The cross lines, with a loop, show that a certain item has been transferred to some other part of the abstract, and the straight cross lines represent the cutting out of the item as it is billed, the checking line being in red.

The heavy lines and ticks indicate the work carried out in red ink. The actual size of the abstract sheet, shown in the illustration, is double foolscap.

BILLING

This brings us to the final stages in the preparation of a bill of quantities. Fig. 5 is the reproduction of the front page of a bill, as issued to the builder.

The abstracts having been reduced and checked, the bills are written direct from them, and if the abstracting has been done properly, this work is quite easy.

Whether each trade has a separate bill, or the whole job is one bill, depends upon the size of the job. A large job is separated into a bill for each trade, but for a small job an "all trades" bill will save a lot of waste paper.

In the Midlands and North, where tendering is often by different firms for each trade, separate bills are necessary.

"**Preliminaries**" will be the first bill written, and this will be collected from various sources,

among which are the specification, form of contract, and general information supplied by the architect.

Water supply, insurances, etc., the value of which are based upon the amount of the contract, are written in this bill, but referred to the "summary" for pricing.

The preamble, or description, of material and methods of mixing concrete, mortar, plaster, paint, etc., is written from the specification, and these paragraphs should only contain the necessary information, without being "wordy."

ESTIMATE

For the Erection and Completion of a House
at Goldsworth Park Estate, Southdown

for

A.B. Cee Esq.,
according to the Drawings and under
the supervision of –

Messrs. Dee and Gee F.F.R.I.B.A.
Architects,
High Street,
Southdown.

September 19

Bill No. 1.

Preliminaries.

£ s d

The measurements are net as fixed in the work and prices should include for waste on materials, carriage and cartage, carrying in, return of samples, hoisting, selling and fixing, except as otherwise provided.

The Form of Contract will be that issued by the R.I.B.A. dated 1909 and these Quantities will form part of the Contract

The site is situated on the Goldsworth Park Estate and is about one mile from Southdown Station on the —— Railway.

There is a private road leading from the main road to the site and the Contractor will be responsible for all damage and the upkeep of same and for leaving same in good repair and condition upon completion of the Contract.

Contractors should visit the site and make themselves acquainted with the approach and general conditions, the soil is believed to be clay.

A copy of the Drawings and Specification will be supplied to the Contractor and must be kept on the site.

The Drawings comprise
[illegible]" Scale General Plans and Sections
[illegible]" Details of Plans and Elevations
Full size details.

General [illegible]" Details will be supplied and all drawings fully dimensioned.

Continued £

1

FIG. 5. FRONT PAGE OF A BILL

Odd figures are not used in billing (except where the work is in small quantities). Cubic and super yards are billed to the nearest yard; that is, 90 ft. cube is called 3 yd. cube; 99 ft. cube, 4 yd. cube; 102 ft. super is called 11 yd. super; 104 ft. super, 12 yd. super. Linear feet are called the nearest foot; that is, 12 ft. 5 in. is called 12 ft., 12 ft. 7 in. is called 13 ft. Squares are billed to the nearest 5 ft.; that is, 1,002 ft. is called 10 squares, 1,006 ft. is called 10 squares 5 ft.

Fig. 6 is an actual copy of a "bricklayer's" bill.

Lead and iron is weighted out to the nearest 7 lb.; that is, 3 cwt. 2 qr. 8 lb. is called 3 cwt. 2 qr. 7 lb.; 3 cwt. 2 qr. 12 lb. is called 3 cwt. 2 qr. 14 lb.

The description in bills is written out in full, except for the word "ditto," which should only be used with great care.

Write "continued" at both top and bottom of each page against the money column. At the end of each "trade" bill the words "carried to summary" are written.

The summary is written similarly to Fig. 7.

The bills are checked in red ink, a small tick being placed on the extreme left against each item, and the item cut out in red ink on the abstract.

It is not only the quantity which has to be checked, but the description also.

The "taker off" should look through the bills finally before they are sent to the printer, to see if the descriptions agree with his intentions.

"Spot items" are grouped together in a separate bill.

EXAMPLE 17. Example 17 shows a fragment of a draft bill giving the various items shown in the Example 16 of an abstract; these items are shown ticked in red at the side. This is, of course, a composite bill simply to illustrate the method employed.

Fig. 8 is a typical "form of tender" issued to the builder.

Schedules. Where there is not time to prepare

Bill No. 4.

Bricklayer.

Rods	feet				£	s	d
				The whole of the bricks are to be good hard and sound.			
				The Red and Grey facing bricks are to be of approved sample and colour.			
				The mortar to be composedof well burnt grey stone or Lias lime and sharp pit sand in the proportions of one of lime to three of sand mixed fresh as required for use.			
				The cement mortar to be in the same proportions.			
1	44	–	sup.	Reduced brickwork in grey stone lime mortar.			
	27	–	"	Ditto but in detached piers			
	1270	–	"	One brick wall in ditto built "Rat Trap"			
	125	–	"	Reduced brickwork in Lias lime mortar.			
	170	–	"	Ditto in cement mortar.			
	10	–	"	Halfbrick Fender walls in cement mortar.			
	90	–	"	Ditto sleeper walls built honeycomb in ditto.			
	490	–	"	Halfbrick walls in cement mortar			
	155	–	"	Extra for walls in Grey lime mortar being built in two halfbrick skins with and including galvanised iron ties, one to each two feet super.			
	155	–	"	Ditto all as last but in Lias lime mortar.			
	10	–	Run	Bull nose bricks on edge as sill.			
	30	–	"	Facing bricks on edge as kerb.			
				No. 2 Obtuse mitres.			
				Continued	£		

15.

FIG. 6. BRICKLAYER'S BILL

Estimate for the Erection and Completion of a House at Goldsworth Park Estate, Southdown, for A.B. Cee Esq., according to the Drawings and under the supervision of–

Messrs. Dee and Gee F.F.R.I.B.A.
Architects,
High Street,
Southdown.

September 19

SUMMARY.

			£	s	d
Bill No. 1	Preliminaries				
Bill No. 2	Excavator & Concretor				
Bill No. 3	Drains				
Bill No. 4	Bricklayer				
Bill No. 5	Mason				
Bill No. 6	Tiler				
Bill No. 7	Carpenter				
Bill No. 8	Joiner & Ironmonger				
Bill No. 9	Founder & Smith				
Bill No. 10	Plasterer				
Bill No. 11	Plumber				
Bill No. 12	Electrical Engineer				
Bill No. 13	Painter				
Bill No. 14	Glazier				
		£			
	Provide water for works				
	Allow for Fire Insurance				
	Allow for Employers Liability and Third Party				
	Ditto for all National Health and Unemployment Insurances				
	Carried to Form of Tender	£			

Tenders to be delivered on form furnished herewith at the Architects Office by first post on Friday the 3rd. of October 19

The Employer does not bind himself to accept the lowest or any tender.

FIG. 7. SUMMARY OF BILL

a proper bill, or where the drawings are not completed, or the quantity of the work to be executed is unknown, *schedules* are prepared as a price basis, and the work is measured after completion, and priced out at the schedule rates. These are often used in connection with large civil engineering works, such as roads, railways, docks, etc.

TENDER.

for

House at Goldsworth Park Estate Southdown.

To

Messrs. Dee and Gee F.F.R.I.B.A.
Architects,
High Street,
Southdown.

Sirs,

— willing to contract for and hereby undertake to execute the several Works required to be done in the execution and completion of a House at Goldsworth Park Estate for A.B. Cee Esq., according to the Drawings, Specification and Bills of Quantities prepared by you and to your satisfaction for the sum of . . . .

. . . . . pounds . . . . shillings and . . . .

. . . . pence. (£ . .)

As witness . . . . hand this . . . . day of

. 19

Name. . . . .

Address . . . .
. . . .

The employer does not bind himself to accept the lowest or any tender.

FIG. 8. FORM OF TENDER

There are various types of schedules, among them being—

(*a*) The carefully prepared priced schedule. These are used in connection with such work as the annual maintenance of large buildings, or estates; and the contractor, in tendering, quotes a percentage either "on" or "off" the printed price, but they contain a large number of items which are not applicable to the particular job under consideration.

(*b*) Specially prepared schedule similar to the last, but only containing items of work which are found in the job for which they are being used.

(*c*) Similar to the last but in the form of an ordinary bill, with rough approximate quantities against each item, and either priced or left for the contractor to fill in his own figures.

(*d*) In the form of a bill of quantities, but without any quantities and left for the contractor to price.

For all these four types, the work is measured during progress, or on completion, and then priced at the rates in the schedule.

To decide the lowest tender of those received upon a schedule, it is necessary to take off approximate quantities of the largest items and more expensive work which has to be executed, and price it out upon the basis of each tender; this, when totalled, will give the comparison. The reason for this procedure will be understood if the example is studied.

EXAMPLE 18. Example 18 shows the method of comparing priced schedules, but this example is not, of course, complete. In dealing with a job, many other items would have to be taken into consideration, but it shows the principle to be adopted and the reasons for so doing.

A student wishing to test his knowledge, can "take off" certain items in connection with the office building, which are not in the examples, or he can square, abstract, and bill the examples.

Yds	Ft			
				Continued £
✓ 11		cube	Excavate and return; fill in and ram to surface trench's	
✓ 11		"	Ditto but wheel and deposit.	
✓ 6		"	Lime concrete in surface trenchs. in the proportion of one of lime to three of ballast.	
✓	63	Sup	Reduced brickwork in lime mortar as described	
✓	25		Damp proof course of two course of Slates in cement laid breaking joint	
✓	55	Run	Ditto but in 4½" widths.	
			To Summary £	

BILLING, EXAMPLE 17

Example No 18.

Example for checking Prices submitted as a schedule

Yds	Feet		Item	Rate A	Contractor A £	s	d	Rate B	Contractor B £	s	d
			Excavation & cart away			10	6			11	-
			Cement Concrete		1	12	-		1	11	6
			Brickwork in Lime		30	-	-		31	-	-
			Facings				1½				1¼
			Slating		3	13	-		3	12	-
			Fir in floors			5	6			5	3
			Flooring		2	4	6		2	4	9
			Sheet Lead		2	18	-		2	15	6
					41	1	7½		42	-	1¼
			Apparently "A" is lowest But fill in approximate quantities.								
100		cube	Excavation & cart away	10/6	52	10	-	11/-	55	-	-
200		"	Cement concrete	32/-	320	-	-	31/6	315	-	-
10		rods	Brickwork	30/-	300			31/-	310	-	-
	2000	sup.	Facings	1½	12	10	-	1¼	10	8	4
100		sqs	Slating	73/-	365	-	-	72/-	360	-	-
	150	cube	Fir in floors	5/6	41	5	-	5/3	39	7	6
5		sqs.	Flooring	44/6	11	2	6	44/9	11	3	9
20		cwt	Sheet Lead	38/-	38	-	-	55/6	55	10	-
					1158	4	6		1156	9	7

"B" therefore is actually lowest

PREPARING A SCHEDULE, EXAMPLE 18

Building Law

By Horace Cubitt, F.R.I.B.A., F.S.I.
Author of "Building in London"

Chapter I—PRIVATE RIGHTS AND LIABILITIES

Introduction. The building law may be considered to be in two groups, namely: Group I, the law governing the relations between private persons or organizations, which differs in each of the three parts of the United Kingdom, namely: (*a*) England and Wales, (*b*) Scotland, (*c*) Northern Ireland; and Group 2, the combination of Acts and by-laws for the public control of building work which also differs in each of the above-mentioned areas, there being further, in England and Wales, very considerable differences between the law in the provinces and that in London, and there being separate local by-laws in each district.

The law in Group 1 affects the relations between the several persons concerned with building work and the ownership of buildings, and comprises, among other things, the law of contracts, the law of easements, and, in the case of buildings let on repairing leases, the law of dilapidations. These laws are contained partly in the *common law* and partly in the *statute law*. The common law is the law that has grown up by custom over a long period of time, and has been confirmed by numerous decisions in courts of law; the statute law consists, of course, of various Acts that have been passed by Parliament.

The law in Group 2 comprises Acts and by-laws, administered by various local authorities, controlling the formation of streets and the erection of buildings. This law is in three main divisions, namely: (*a*) the law in the provinces, which is contained in various Acts of Parliament and in by-laws which vary for every district; (*b*) the law in the County of London, which consists of Acts of Parliament, supplemented by several groups of by-laws and regulations; and (*c*) the law contained in various comparatively recent Acts of Parliament which apply throughout the whole of England and Wales, including London.

In Scotland and, in a less degree, in Northern Ireland, the law in Group 1 differs very much from that in England and Wales, and no attempt is made to deal with it in these notes.

Law of Contracts

A contract is an undertaking on the part of a person or body to execute certain work or perform certain services for an agreed remuneration. The two common cases in which a contract occurs in building work are—

(*a*) Where an architect is employed by a person, who may be termed a building owner, to design and arrange for the erection of a building; and

(*b*) Where a builder undertakes to carry out certain building work required by a building owner.

Although a verbal contract for work that can be executed within twelve months is binding, contracts should always be in writing, as the uncertainty associated with any verbal arrangement is a great objection to it.

Stamping of Contracts. Ordinary contracts are required to bear a sixpenny stamp. Contracts under seal are required to bear a ten-shilling stamp. The stamping may be done by affixing an ordinary stamp, or by sending the document to Somerset House to be stamped, which can be done through the medium of any post office.

Contracts entered into by a local authority under the Public Health Acts or the Metropolis Management Acts, except for trifling matters, are required to be under the seal of such authority, and contracts with a local authority which are not under seal are not binding. There have been numerous decisions in the Courts where persons who have sued under contracts not under seal with local authorities have failed to secure any remuneration for their work. Therefore any person having a contract with a local authority for work or services should insist on the contract being under seal.

Architect and Owner. The contract between an architect and a building owner is usually formed by means of letters between the two

parties. The letter requiring an architect to perform certain services, and his reply undertaking to perform such services at a specified rate of remuneration, when followed by instructions to proceed, is a definite legal contract. In cases, however, where the architect and building owner are well known to one another such a definite contract sometimes fails to be made, as neither person likes to offend the susceptibilities of the other by requiring a verbal arrangement to be confirmed in writing. This is likely to be unfortunate in the event of a subsequent dispute.

In a case where an architect is employed by a large firm or organization his contract of engagement is often formed by letters only, but in the case of important works it is not unusual for a more formal contract to be executed.

Building Owner and Builder. For work to be carried out by a builder for a building owner there are various forms of contract, the most common being the following: (*a*) Lump Sum Contract, (*b*) Bills of Quantities Contract, (*c*) Schedule Contract, (*d*) Cost Plus Percentage Contract, (*e*) Cost Plus Fixed Fee Contract.

A Lump Sum Contract is the simplest form and is almost always adopted in the case of small works. In works of repair and redecoration, the builder's price is often based on a specification only. In other cases, comprising alterations, additions, and new buildings, it is based on drawings and specifications. In larger works quantities may also be prepared, but in a Lump Sum Contract any quantities prepared are merely for a guidance of the builder and do not form a part of the contract. If there are no variations in the work under a Lump Sum Contract the builder is entitled to be paid the exact contract sum. In practice, however, there are usually some variations, and these are valued by the architect, or by the quantity surveyor if there is one engaged.

A Bills of Quantities Contract is the most widely used for important work. In this type Bills of Quantities are prepared, and priced in competition by builders. The total figure of prices regulates the tender of each contractor, and this total, in the case of the selected contractor, forms the contract sum. Also the several items in the priced Bill of Quantities of the selected contractor form the basis for the valuation by the quantity surveyor of any variations that may occur.

A Schedule Contract is one in which the sum to be paid to the builder is governed by the amount of work which he executes, priced at the rates of a Schedule of Prices. This schedule is either specially prepared for the particular building, or it is a printed schedule of works and prices. In the first case approximate quantities are usually prepared, to each item of which the builder puts the unit figure for which he is prepared to execute the item of work. In the second case there may or may not be approximate quantities, and the builder quotes the percentage "on or off" the schedule prices. In a Schedule Contract the work is usually measured during execution, and the sum to be paid to the contractor is calculated at completion from the prices in the schedules. A Schedule Contract has the advantage of enabling building work to be put in hand before a building scheme has been fully worked out and quantities prepared, and it was often adopted by Government Departments during the war. It has, however, the disadvantage that the sum to be paid to the contractor is unknown until the completion of the work, and for this reason it is not often adopted by private building owners.

The Cost Plus Percentage Contract was much used during the war, but is open to the criticism that the higher the cost the larger is the contractor's remuneration. Its use should be restricted to cases where the building owner is well acquainted with the builder, and has confidence that he will carry out the work in an economical manner.

The Cost Plus Fixed Fee Contract has been evolved to overcome the objection to the last-mentioned kind of contract. In this form of contract a fixed fee is agreed and the contractor receives this fee, neither more nor less, regardless of the ultimate cost of the work. It is considered that in this form of contract the interests of the building owner and the contractor are very similar. In normal cases they will both desire that the amount of work shall not be materially exceeded, and that the work shall be completed within the contract time.

Rise and Fall Clauses. In conditions of uncertainty as to cost of materials, rates of wages, etc., such as applied during the war, contracts have included rise and fall clauses, whereby the total paid on a contract is required to be adjusted in accordance with the rise and fall in materials or wages. The rise and fall clause is much open to objection, from the standpoint of the building owner, as he does not know what the cost of the work will be until it is completed. The adoption of a clause of this nature is, of

course, less justifiable in the case of small works which can be quickly completed than in the case of a building scheme extending over a period of several years.

Placing and Management of Contracts. In 1944, a committee, formed under the direction of the Ministry of Works, issued a Report on the Placing and Management of Building Contracts. This Report, a copy of which may be obtained from H.M. Stationery Office, price 1s., deals with building contracts from various aspects. It lays great stress on the need for the thorough working out of a building scheme in full detail before a contract is signed, and points out that the time properly spent in this way will tend to shorten the actual execution of the work, particularly if the building owner fully makes up his mind during the preparation of the drawings and specification, so that there will be no material alteration in the scheme after the contract has been signed. The Report also stresses the need in all large contracts for the use of a Time and Progress Schedule. This is a chart, often in graphic form, showing the date on which the contractor is to have possession of the site, and the date on which the work is required to be completed, with a number of intermediate dates for the delivery of various materials and fittings and the completion of various items of the work. This fixing of dates enables the various operations to be fitted in with one another, and also it is possible, week by week, to check the actual progress with the expected progress, so that any lack of speed in the carrying out of the work may be at once realized, and, as far as possible, remedied.

Form of Contract. In the case of small works the contract often consist only of letters. An architect, acting for a building owner, writes to two or more builders asking for tenders for the work. Each builder sends in his tender offering to do the work for a certain amount. This is usually in the form of a letter, which is sometimes accompanied by a priced estimate of the several items of the work to show how the sum is made up. The selected builder is then informed by letter that the architect, acting on behalf of the owner, accepts his tender. The two documents—the tender to do the work at a certain figure, and the letter of acceptance—constitute the contract. This will also be the case when an architect obtains and accepts by letter a tender from one builder only.

In the case of work, however, costing more than a small amount it is desirable to have a definitely drawn up contract. While some public authorities still use their own special contract form, others, and almost all private building owners, use the form of contract drawn up by the Royal Institute of British Architects in consultation with the National Federation of Building Trades' Employers. There are two variants of the R.I.B.A. form, each with an attached list of conditions, one form applicable for a Lump Sum Contract and the other for a Bills of Quantities Contract. In the first case the contract documents comprise the drawings, specification, and conditions; in the second case they comprise the drawings, bills of quantities, and conditions, the specification not being, in such case, a contract document, but being only for guidance in the carrying out of the works.

The conditions in each variant of the R.I.B.A. form are very similar, the only material differences being in the references to the specification and bills of quantities. The conditions deal, among other matters, with the powers of the architect and the responsibilities of the contractor. They provide for the insurance of the contractor's liability under various Acts of Parliament, and for the insurance of the building against fire. They deal with the method of ascertaining the value of any extra works, the method of payment of the contractor, and they contain a rise and fall clause for the purpose of adjusting the contract sum in the event of there being any increase or decrease in the prices of materials or rates of wages. The forms each contain a clause dealing with sub-contractors and suppliers nominated or selected by the architect, and there is also a clause for arbitration in the event of a dispute between the building owner and the contractor. Each variant of the form contains an appendix with blank spaces to be filled in, among these being spaces for the insertion of the dates for the possession of the site and the completion of the work.

The clause in each variant of the R.I.B.A. form, dealing with the payment of the contractor, provides for payment being made from time to time at the rate of a certain percentage of the value of work executed. These periodic amounts due to the contractor are required to be ascertained by the architect, and certified by him. In issuing his certificate for payment, an architect is required to act in an impartial manner between the building owner and the contractor, whereas in other matters concerning the work, he acts as the agent of the building owner, whose interests are his primary duty.

Chapter II—THE LAW OF DILAPIDATIONS

Definitions. When premises are let by one person to another for a period of time, the use of the premises after the elapse of this period of time is termed the *reversion*. Any damages which accrue to such premises during such period are denoted by the legal term *waste*. Waste is sometimes subdivided as follows: *voluntary waste*, consisting of acts of commission—when a tenant does something; and *permissive waste*, which is an act of omission—as when a tenant neglects to do what he is bound to do in the way of keeping the premises in repair.

Tenant's Liability. In the case of all buildings let to a tenant, there is an implied liability that the tenant will use the premises in such a way that the value of the reversion is not affected. Tenants from year to year have the limited liability of keeping the premises weathertight. The liability of a tenant for a term of years is very much more extensive, and, unless it is limited by the terms of the tenancy, it extends to doing all works which may be fairly described by the name of repairs. In almost every case of a new tenancy for years, the liability of a tenant is definitely expressed in his lease, the terms in the lease dealing with the repairs being usually called the *repairing covenant*. A repairing covenant of an ordinary nature usually provides that the tenant shall repair, maintain, cleanse, and keep the premises and all erections, or additions, subsequently erected in good substantial and tenantable repair, and in such good substantial and tenantable repair shall deliver up the premises to the lessor at the expiration of the term. Further, it is customary to include special clauses requiring the tenant to paint with two coats of good oil colour, the outside wood and ironwork once in every three years, and the inside work once in every seven years, such painting to be done in addition during the last year of the tenancy.

Construction of Repairing Covenant. It will be evident that cases will often arise in which the construction of a repairing covenant will be disputed. In determining the effect of any particular clause, it will often be necessary to study the reports of cases that have been decided by the Courts, of which there are a large number. In the case of *Proudfoot* v. *Hart*, the Court of Appeal decided that, where a three-years' agreement required the tenant to keep and leave the premises in good tenantable repair, the tenant's liability was to keep and leave the premises in such a condition that it would satisfy a reasonably minded tenant of the class likely to occupy the house. In the subsequent case of *Calthorpe* v. *McOscar*, however, the Court of Appeal decided that this criterion of a tenant's liability was applicable only in the case of a tenancy where the class of tenant contemplated at the beginning of the term had not changed. The two cases of *Lurcott* v. *Wakeley and Wheeler* and *Lister* v. *Lane* are of importance in indicating to what extent a tenant is liable to repair premises which are suffering from the effects of age. In *Lurcott* v. *Wakeley and Wheeler*, which was decided in 1911, the front wall of the building had become dangerous, and the London County Council had served a Dangerous Structure Notice requiring it to be pulled down. The Court of Appeal decided that as this front wall was merely a subsidiary portion of the premises, its rebuilding had not changed the character of the building, and that the tenant was liable for the cost of its re-erection. The depth of the building from front to back in this case was 140 ft.; if the building had been on a shallow site, and the front wall, in consequence, had been a very considerable proportion of the structure, possibly a different decision might have resulted.

In *Lister* v. *Lane*, the house in question had become seriously defective owing to age, and the tenants were served with a notice requiring them to repair, among other things, one of the walls which was bulging outwards. The house had been originally built on a timber foundation resting on mud, and could not be repaired except by underpinning with brickwork, carried down through a 17ft. depth of mud in order to reach the solid gravel. The Court of Appeal in this case decided that the work in such case would not be repairing, as the house, when such works were done, would be a different thing from the house at the commencement of the lease. The tenants, therefore, were held to be not liable.

While most repairing clauses are somewhat

similar to those that have been already quoted, clauses are sometimes encountered in leases which impose, on the one hand, a considerably increased, and, on the other hand, a greatly decreased, liability on the tenant. It has been held that where a lease, in addition to the ordinary clauses as regards maintenance, also requires the tenant to pay one of the following terms: charges, impositions, or outgoings, he will be liable to pay the cost of all works required by public authorities, as, for instance, the reconstruction of the drainage system under a notice from the local authority. On the other hand, tenancies for a short period, such as three years, often contain a clause by which the tenant's liability to keep the premises in good repair is limited by the term "fair wear and tear excepted." The tenant's liability where this clause occurs is relatively slight, and in fact consists only of making good any damage that may have occurred.

Schedule of Dilapidations. It is often necessary, in the case of a building let on a repairing lease, for a tenant to be served with a Notice of Repair accompanied by a Schedule of Dilapidations, which is a document setting forth the repairs that are required to be executed to comply with the repairing covenants of the lease. The common occasions for the serving of such a notice are either (*a*) at about nine months before the end of a tenancy, when it is desired to bring home to the tenant his liability under his lease, while there is yet time for him to put in hand and complete the necessary repairs; or (*b*) when the foregoing procedure has not been adopted, and the lease has expired without the necessary repairs having been carried out, and a claim for damages is about to be made. A further occasion for the serving of a notice and a Schedule of Dilapidations is when property is so neglected during the term of a lease that there is a risk of injury to the reversion. A schedule, in such a case, is termed an "interim" schedule, from the Latin word signifying "in the meantime."

An architect or surveyor who is instructed to prepare a Schedule of Dilapidations should obtain from the person instructing him, usually the owner's solicitor, a copy of the repairing covenants, and should ask to be given the opportunity of inspecting the lease itself so that he may ascertain such particulars as the character of the property, the length of the term, and other matters affecting the tenant's liability.

The architect or surveyor then visits the premises and makes written notes of the various items of disrepair. The customary method is to deal first with the exterior of the building, including the roof, and then to deal with the interior, beginning with the topmost storey and working downwards floor by floor. The work requires to be systematically and carefully done, the defects of each external elevation, of the roof, and of each room being entered separately in a notebook. If the survey is for the preparation of an interim schedule, only defects in the structure or in the external appearance of the building will require to be noted; for the object of the notice, in this case, is only to prevent injury to the reversion. If, however, the schedule is of an ordinary nature, served with a notice near the end of the lease, or after its expiration, more comprehensive notes are necessary. In addition to important items there will be numerous small matters to be noted, such as cracked hearths, missing sash fasteners, broken sash lines, defective locks, etc. Nothing is too small for inclusion. Then in his office, the surveyor, with the aid of his notebook, prepares his Schedule of Dilapidations. This usually follows the order of the notes, and is written in the imperative mood, the following being typical clauses: "Cut out the cracked brickwork of arch over dining-room window, and reinstate with new bricks to match existing"; "repair the broken floor boards"; "wash, stop, and twice whiten ceiling." The clauses are usually prefaced by a side heading, giving the portion of the building to which the required works refer.

The Schedule of Dilapidations, when prepared, is then sent to the tenant with a Notice of Repair requiring him to do the works set out in the Schedule. It is a general practice for the notice to be served by the owner's solicitor, but sometimes it is served by the surveyor.

If there is a claim for damages, this is based on an estimate of the cost of executing the works of repair in the schedule, which estimate is prepared either by the surveyor himself, or by a firm of builders on his instructions. But, under the provisions of the Landlord and Tenant Act, 1927, a claim may not exceed the amount by which the value of the reversion is diminished, so that, if the building is to be pulled down with a view to the erection of a new building on the site, no claim for damages can be substantiated.

Chapter III—THE LAW OF EASEMENTS

Definitions. Where there are two properties, and the owner of one property has in some way or other obtained a right over another property, such right is termed an *easement.* The legal term *tenement* is employed to denote a property affected in any way by an easement. The property of the owner possessing the easement is called the *dominant tenement* ; the property of the owner suffering the easement is called the *servient tenement.* The word " tenement," it will be seen, is not used in this case as denoting a portion of a building, but to denote a piece of property consisting either of land and buildings, or land alone. There are several kinds of easements: easements of way, easements of water, easements of support, easements of light, easements of air. An easement is a privilege or a right to do something without profit; a right to pasture cattle, to dig for sand, or to cut turf, being a right with profit, is not an easement.

Easements should also be distinguished from inherent rights of property, and from natural rights which one property has against another. For example, an owner of property has a right to light coming perpendicularly down over his tenement as his ownership extends in an unlimited direction skywards, but the right to light coming to him in an inclined direction across the site of another tenement to the windows of his building can exist only as an easement. Further, an owner of land has a natural right to have his land supported by the land on either side; and the adjoinng owner may not excavate his land and let down the land of his neighbour. But an owner of land cannot require as a natural right the support of the adjoining land to a building which he may have erected; such right of support can only be obtained as an easement.

Classification of Easements. Easements are classed by the lawyers in different categories according to their character, there being three pairs of common classifications. There are *positive easements* and *negative easements,* the first class being easements which give a right to do something, as for instance a right to discharge water on to land, and the second class being easements, such as one of light, which prevent the owner of the servient tenement from doing something in an unrestricted manner on his own land. Another classification is that of *continuous easements* and *discontinuous easements*, an example of the first being a right of light which is, of course, continually enjoyed, and an example of the second being a right of way which is enjoyed only when it is used, A third classification is that of *apparent* and *non-apparent easements.* An apparent easement is one which is denoted by some visible thing, such as a window to receive light. An example of a non-apparent easement is a deed under which the owner of one tenement agrees, for the benefit of the adjoining tenement, to be subject to some restriction of his rights.

Origin of Easements. Easements can come into existence in several ways, namely—

(*a*) By direct grant.
(*b*) By implied grant.
(*c*) By prescription.

Easements obtained by direct grant are usually the result of a formal legal deed. Easements arising by implied grant occur where both tenements were at one time under a common ownership. Where two tenements under a common ownership had certain conveniences in relation to one another, and one of the tenements is sold, the law implies that such conveniences, which are termed "*quasi easements,*" are sold with the tenement if reasonably necessary for the use of the tenement that is sold. For example: If two tenements, A and B, were in one ownership and B could be approached only by means of a roadway through a portion of A, then, when B is sold, this roadway, being essential to the use and enjoyment of B, becomes an easement.

Easements by Prescription. An easement acquired by enjoyment over a long period of years is said to be obtained by prescription. At one time it was necessary in theory to prove that the easement had been enjoyed from time immemorial. The Courts, however, then came to accept the theory of a lost grant on the basis that if an alleged right had been openly enjoyed for a long period, there was a presumption that at some time in the past a grant had been made.

The position was put on a more definite basis by the Prescription Act, 1832, which laid down definite periods of enjoyment, at the expiration of which a claim for an easement could be made. The most common application of this Act is in regard to rights of light; the provision of Section 3 of the Act on this subject are as follows—

> And be it further enacted, that when the access and use of light to and for any dwelling-house, workshop, or other building, shall have been actually enjoyed therewith, for the full period of twenty years without interruption, the right thereto shall be deemed absolute and indefeasible, any local usage or custom to the contrary notwithstanding, unless it shall appear that the same was enjoyed by some consent or agreement expressly made or given for that purpose by deed or writing.

Further sections of the Act deal with other forms of easements, giving two periods of years, varying in accordance with the kind of easement, the first period of enjoyment conferring the right to put forward a claim which may, nevertheless, be contested, and the second, a longer period, conferring an absolute right. In the case of "any way or other easement, or any water-course or use of water," the first-mentioned period is twenty years and the second is forty years.

Easements of Light. In building work the question of easements of light is one of very great importance. An owner of property who allows an adjoining owner to erect buildings with windows overlooking his land, and in consequence obtain light from over his land, if he permits such windows to receive light for a period of twenty years, will have allowed an easement of light to have been acquired over his property. To prevent such right of light being acquired, it is a common practice for an owner to protect himself either by erecting a screen to prevent the access of light over his land to the adjoining building, or by obtaining from the owner of the adjoining building a written undertaking that he will not acquire any rights of light. An interruption to the obtaining of an easement of light must be in existence for not less than one year to be valid. It follows from this that an enjoyment of light for nineteen years and one day will enable an easement to be obtained, as after this period a valid interruption is not possible.

Where a building is required to be erected on land subject to an easement of light, the question as to what height it is possible to build, without infringement of the rights of light, is of course of great practical importance. At one time it was considered that an infringement of light would take place if the angle of light, measured from the vertical face of the window at sill level, was less than 45°. In 1904, however, the very important case of *Colls* v. *Home and Colonial Stores* was decided by the House of Lords, in which the principle was laid down that, although the actual angle of light was of value as being some indication of amount of obstruction, this in itself was not the vital point. The case decided that the dominant owner was entitled to have sufficient light left to him for the ordinary purposes of life. The test of an obstruction to a right of light is, therefore, not the angle of light, but whether the light left in each room is sufficient for the ordinary purposes of mankind.

It is important that persons concerned with building should know what risks they may be running in carrying on with a new building, to which objection is raised by a dominant owner. Such dominant owner can apply to the Courts either for an injunction to prevent the obstruction to light, or for damages for the depreciation of the value of his property. Should the Courts consider that the threatened loss of light is relatively small, they may refrain from granting an injunction, and leave the dominant owner to claim damages. But if an injunction is granted, the offending portions of the new building, if already erected, may be required to be pulled down.

Easements of Air. Easements of air are not frequently encountered in connection with buildings. An easement of air can only be obtained where the air passes through a definite channel, such as an opening, or grating, in a wall.

Easements of Support. Rights of support occur in the case of a building abutting on vacant land, where an easement can be acquired for the lateral support of the building by the vacant land. A more common case, however, is the support which one building gives to another that is built against it, where, as is not infrequent in old buildings, some kind of lateral support is essential to stability. Where the upper part of a building is in a different ownership from the lower part, such upper part has, of course, a right to be supported by the lower part. The law as to the acquisition and enjoyment of easements of support is rather complex, and a careful study of the reports of the leading case on the subject, *Dalton* v. *Angus*, which was decided in 1881, is recommended.

Extinguishment of Easements. Easements may be extinguished in several ways: by a deed renouncing the enjoyment, by abandonment of use, or by the union of the two tenements in a common ownership. The question whether an easement has been abandoned may often be difficult to determine. In considering this question, the length of time during which the enjoyment of the easement has been discontinued is of importance, but of more importance are the actions of the owner of the dominant tenement: whether they have been such as to indicate his intention to renounce the easement. The bricking up of a window opening in a permanent manner would no doubt indicate an intention to abandon an easement of light. On the other hand, the cessation of the enjoyment of an easement of light for a time, by reason of the demolition of the building and its non-erection for some years, would not be an indication that the dominant owner intended to abandon the easement, as there is sometimes an interval of several years between the demolition of a building and its re-erection. In the rebuilding of a war-destroyed building all previously existing easements will, of course, be enjoyed, unless there is something to show that, in the interval between the destruction and rebuilding, there has been evidence of an intention of the owner to abandon them. In the special circumstances, non-erection of the building, even over a long period may not indicate abandonment.

In all cases of re-erection care must be taken to arrange that the windows through which the light is received are in the same position in the new building as they were in the old building, or otherwise the easement will be considered to be extinguished.

Party Walls

A party wall is a wall which separates two buildings from one another, and in which the owners of such buildings have, respectively, certain rights. In the provinces the rights of owners in regard to party walls are governed partly by Section 38, and the First Schedule, Part V, of the Law of Property Act, 1925, and partly by the common law. In the County of London these rights are controlled and regulated by the London Building Acts. The subject of the rights of owners in regard to party walls outside London is one of considerable complexity, and, in practice, it will often be necessary, in an important case, to obtain legal opinion as to the legality of any works that may be proposed. In most provincial cases the wall is regarded, for purposes of ownership, as being severed vertically down the centre line, and each owner is considered to own the half of the wall on his side of the centre line, and has certain rights of support and user over the other half.

In London the rights of owners are much more extensive, and are set out in detail in Part VI of the London Building Acts (Amendment) Act, 1939. This Part contains certain definitions, and is, as regards the remainder, in three portions headed respectively: (*a*) Rights, etc., of owners, (*b*) Differences between owners, and (*c*) Expenses. It will be noted that the following expressions are of frequent occurrence: "party structure," "party fence wall," "party wall," "building owner" and "adjoining owner." The first two of these expressions are defined in Section 4 of the Act, where "party structure" is stated to mean, among other things, a party wall. The definition of "party wall" in Section 4 is there stated, however, not to apply to Part VI, and in Section 44 of the Act there is a special definition for the purpose of Part VI, which is as follows—

> "party wall" means
> (i) a wall which forms part of a building and stands on lands of different owners to a greater extent than the projection of any artificially formed support on which the wall rests; and (ii) so much of a wall not being a wall referred to in the foregoing paragraph (i) as separates buildings belonging to different owners.

The expressions "building owner" and "adjoining owner" are defined in Section 5 of the London Building Act, 1930, as follows—

> "building owner" means such one of the owners of adjoining land, as is desirous of building, or such one of the owners of buildings, storeys, or rooms separated from one another by a party wall or party structure, as does or is desirous of doing a work affecting that party wall or party structure.
> "adjoining owner" and "adjoining occupier" respectively mean any owner and any occupier of land, buildings, storeys or rooms adjoining those of the building owner.

Sections 45 and 46 of the London Building Acts (Amendment) Act, 1939, set out the rights of the building owner, there being two cases, one where adjoining lands are not built on, or are built on only to the extent of a boundary wall, which case is dealt with in Section 45, and the other case, where adjoining lands are built on, which is dealt with in Section 46. In the first-mentioned case, if the building owner desires to

build a party wall or a party fence wall, he is required to serve a notice on the adjoining owner. Then if such owner consents, the wall may be built as proposed, but, if he does not consent, the building owner is entitled to build only an external wall placed wholly on his own land, although in such case he may project the foundations of the external wall into the land of the adjoining owner, after one month's notice.

Under Section 46, where lands of different owners adjoin and are already built on, the building owner is given certain rights to underpin, thicken and repair, or to demolish and rebuild, a party structure or party fence wall, subject to making good all damage to the adjoining premises. It is specially provided, however, in both this and the preceding section that the building owner has no right to place special foundations on the land of the adjoining owner without his previous consent in writing. Special foundations are defined in Section 44 as being foundations in which an assemblage of steel beams or rods is employed for the purpose of distributing any load.

Section 47 gives the periods which must be observed after the service of a notice before any work is begun, these being one month in respect of a party fence wall or special foundations, and two months in respect of a party structure. Section 48 entitles an adjoining owner to serve on the building owner a counter-notice requiring the execution of certain works.

Section 50 deals with the case where it is proposed to erect within ten feet of an adjoining owner's building, a building which will extend lower than the bottom of the foundations of the adjoining owner's building, and also where, within twenty feet of an adjoining owner's building, it is proposed to erect a building which will extend to such a depth below ground as to be cut by a plane drawn at an angle of 45° from the line formed by the intersection of the external face of the adjoining owner's wall with the level of the bottom of the foundations of such wall. In either of these cases the adjoining owner may require the foundations of his building to be underpinned.

Under Section 49, if an owner on whom a notice has been served does not within fourteen days express his consent in writing, he is deemed to have dissented from the notice, and a difference is deemed to have arisen between the two owners, which must be settled in a manner prescribed in Section 55. This section provides that if the two owners cannot agree on the appointment of a single surveyor to settle the dispute, they shall each appoint a surveyor, and the two surveyors shall select a third, and then "the three surveyors, or any two of them" shall by their award determine all matters in dispute. It is the general practice in London, where party wall notices are served, for the two owners, almost as a matter of routine, to appoint their surveyors so that all matters may be covered by an award.

Section 56 deals with the apportionment of expenses of the execution of the several works referred to in Sections 45, 46 and 48, and it should be noted that when use is made by an owner of a party structure at some period after the structure is built, regard is to be had, unless otherwise agreed, to the cost of labour and materials prevailing at the time when the use is made.

Where a party wall is required by the building owner to be rebuilt to suit his own purpose, he is liable for the whole cost of the work. It is, however, specially provided that expenses incurred in the underpinning, thickening or rebuilding of a party wall "on account of defect or want of repair" of the wall are to be apportioned between the two owners, regard being had to the use which each owner makes or may make of the wall.

The foregoing is a brief summary of the principal provisions of Part VI of the Act. Any person who is concerned with party wall matters in London will be well advised to read through the whole of Part VI, and to study particularly the provisions of Sections 45, 46, 48 and 50, and also the definitions of the various terms as given in the Acts of 1930 and 1939.

It should be noted that there is no definition of owner in the 1939 Act, this being given in Section 5 of the 1930 Act. The definition is as follows—

"owner" includes every person in possession or receipt either of the whole or of any part of the rents or profits of any land or tenement, or in the occupation of any land or tenement, otherwise than as a tenant from year to year, or for any less term, or as a tenant at will;

From this it is evident that, where a building is let off in various tenancies, on agreements or leases for terms of more than one year, there will often be a number of persons, in addition to the lessor, who come within the definition of owner, and are therefore entitled to receive a party structure notice. Where a building is leasehold the freeholder, of course, is also entitled to notice.

Chapter IV—LAW IN REGARD TO NEW STREETS AND BUILDINGS

Main Divisions

Acts and By-laws. As has already been indicated the law in regard to new streets and buildings in England and Wales is in three main divisions, these being (1) the provincial law, consisting principally of the Public Health Acts and by-laws; (2) the London law, comprising the unrepealed portions of the Metropolis Management Acts, the London Building Acts, and the Public Health (London) Act, 1936; (3) Acts applying throughout the whole of England and Wales, the principal being the Town Planning Acts, the Restriction of Ribbon Development Acts, the Housing Act, 1936, and the Factories Act, 1937. Also in a few of the large provincial towns the law dealing with building work is extended by private Acts.

In any matter of importance affected by an Act of Parliament, it is always desirable to consult the text of the Act. Copies of any Act may be obtained either directly or through a bookseller from H.M. Stationery Office, of which the principal address in England is York House, Kingsway, London, W.C.2.

Law in Scotland and Northern Ireland. Before dealing in some detail with the law in England and Wales, a very brief reference will be made to the law in Scotland and in Northern Ireland.

BUILDING LAW IN SCOTLAND. This varies according to the class of district, whether a "burgh" or a "county." The law in burghs is contained in the Burgh Police (Scotland) Acts of 1892 and 1903, which Acts have to be read together, as the former Act is in certain respects amended by the latter, and in by-laws made under such Acts. Model by-laws were prepared in 1937 for the guidance of Town Councils, and copies of this model may be obtained from H.M. Stationery Office, whose address in Scotland is 120 George Street, Edinburgh. A few of the large towns have private Acts which operate in the place of the Burgh Police Acts. The law in counties is contained in the Public Health (Scotland) Act, 1897, and in by-laws made under such Act. In certain burghs and counties by-laws applying to buildings for habitation have also been made under the special Scottish housing Acts.

In Chapter VIII, which deals with Acts of general application, it will be noted that most of the Acts there mentioned apply throughout Great Britain, and in consulting the text of these Acts it will be found that in each case there is a special section which regulates the application of the Act to Scotland. It will be further noted in such chapter that the Town and Country Planning (Interim Development) Act, 1943, and the Town and Country Planning Act, 1944, apply only in England and Wales, the reason being that there are special Acts of a similar nature for Scotland: the Town and Country Planning (Interim Development, Scotland) Act, 1943, and the Town and Country Planning (Scotland) Act, 1945.

BUILDING LAW IN NORTHERN IRELAND. The basis of the law is the Public Health (Ireland) Act, 1878, under which Act all local authorities were empowered to make by-laws. The Public Health Acts Amendment Act, 1907, hereinafter mentioned, applies, where adopted, to Northern Ireland. The requirements of these Acts in regard to the erection of buildings are supplemented in a few areas by local Acts. The subjects of housing and town planning are dealt with in various Acts applicable only to Northern Ireland.

Provincial Building Law

PRINCIPAL ACTS. The basis of the building law in England and Wales, outside the County of London, is the Public Health Act, 1875, with its principal amending Acts of 1888, 1890, and 1907, and with also the Public Health Act, 1925, and the very important Public Health Act, 1936, which in many respects supersedes the Act of 1875. The provisions of the foregoing Acts are amplified by detailed requirements in the form of by-laws, varying in each district but based on Model Codes issued by the Minister of Health and published by H.M. Stationery Office.

ADMINISTRATIVE AUTHORITIES. Before dealing in some detail with the Public Health Acts, it is desirable to refer to the administrative authorities.

By Section 1, of the Local Government Act,

1933, England and Wales, excluding London, are divided into administrative counties and county boroughs. The counties are subdivided into county districts, which are either non-county boroughs, urban districts or rural districts. The council of each county borough and county district is charged with the administration of the Public Health Acts and by-laws. So far as these Acts and by-laws are concerned the duties and powers of county boroughs, non-county boroughs and urban districts are the same. A city, for administrative purposes, is a county borough. Where in certain sections of the Public Health Acts the words "urban authority" are used they include the council of a city or borough. The powers of a rural district council are less extensive, except in districts, of which they are many, where the rural authority has obtained some urban powers. Districts in which the authority has only rural powers are generally those of an agricultural character, where there is little building development. Throughout these notes the single term "the local authority" will be used to denote the authority, whether city, borough, urban or rural, which administers in its district the Public Health Acts and by-laws.

DEVELOPMENT OF THE PRESENT LAW. For nearly sixty years the Public Health Act, 1875, formed the main basis of local government administration, and contained also the principal requirements in regard to streets, buildings, drainage and sanitary work, the various amending Acts together with the Public Health Act, 1925, being amplifications of the main Act.

In 1930, a Committee was appointed by the Government to advise on technical changes that should precede a consolidation of the Public Health Acts. This Committee prepared draft Bills, the first of which, after various modifications in Parliament, became the Local Government Act, 1933. This Act repealed and re-enacted with considerable changes all provisions of the Public Health Act, 1875, regarding local government areas, elections of members, levying of rates, borrowing of money, and similar matters of local administration. A further Bill was then prepared dealing among other things with the repeal and re-enactment with modifications of some of the more important provisions of the 1875 Act in regard to building work and sanitation, and from this Bill there resulted the Public Health Act, 1936. It was presumably intended that this Act should be followed by a further Public Health Act, amending the requirements, and in particular those regarding streets, which still remain unrepealed in the Act of 1875, and its amending Acts. Owing, however, to the war, the enactment of a further Public Health Act has been left in abeyance.

As matters now stand the statutory law in regard to public health is comprised in the unrepealed provisions of the Act of 1875, and of its amending Acts, with, in addition, the Public Health Act, 1925, and the Public Health Act, 1936, all of which Acts must be read together.

Public Health Act, 1875. The principal unrepealed sections of this Act which affect building work are Nos. 26, 150, 155, 157 and 160. Section 26 prohibits the construction of vaults or cellars under the carriage way of any street without the consent of the urban authority. Section 150 provides that where any private street in any urban district is not sewered, paved, or lighted to the satisfaction of the local authority, such authority may cause plans and estimates of the necessary works to be prepared, and may serve notice on the owners of premises fronting the street requiring them to carry out such works. If such notice is not complied with, the local authority may execute the works themselves and recover the expense from the owners. These powers of a local authority are usually put into force, in the case of streets laid out as part of a building development scheme, when both frontages of a street are almost completely built upon.

The provisions of the Private Street Works Act, 1892, which may operate in the place of those of Section 150, are mentioned later.

Section 155 empowers an urban authority, when any house or building or the front of any house or building is taken down to be rebuilt or altered, to prescribe the line to which the building shall be erected, paying compensation for any loss or damage that the owner may sustain.

Section 157 gives power to an urban authority to make by-laws "with respect to the level, width and construction of new streets and the provisions for the sewerage thereof." The portions of this section which empowered an authority to make by-laws dealing with the walls, foundations, roofs and chimneys of new buildings, and for drainage and sanitation have been repealed by the 1936 Act, and replaced by more extensive requirements.

Section 160 incorporates Sections 64 to 83 of the Towns Improvement Clauses Act, 1847, and

in particular the requirements in regard to buildings, walls or other things which are dangerous to passengers.

The requirements of the Act of 1936, in regard to dilapidated buildings and buildings which are dangerous to occupiers or to persons in an adjoining building, are referred to later.

PUBLIC HEALTH (BUILDING IN STREETS) ACT, 1888. This Act provides that it shall not be lawful in any urban district, without the consent of the local authority, to erect or bring forward any house or building in any street, or any part of such house or building, beyond the front main wall of the house or building on either side in the same street, nor to build any addition to any house or building, beyond the front main wall of the house or building on either side.

PUBLIC HEALTH ACTS AMENDMENT ACT, 1890. This Act is in several Parts, and Parts II to V become operative only when adopted by the local authority. Many of the Sections in Part III, which deals with sanitation and building work, have been repealed by the 1936 Act. Among the unrepealed Sections of Part III are Section 34, which requires the provision of hoardings during the carrying out of building work, and Section 37, which deals with the safety of platforms etc., erected or used on public occasions. The requirements of the latter section are as follows—

(1) Whenever large numbers of persons are likely to assemble on the occasion of any show, entertainment, public procession, open-air meeting, or other like occasion, every roof of a building, and every platform, balcony, or other structure or part thereof let or used or intended to be let or used for the purpose of affording sitting or standing accommodation for a number of persons shall be safely constructed or secured to the satisfaction of the surveyor of the urban authority.

PRIVATE STREET WORKS ACT, 1892. This Act applies only where it has been adopted by the local authority, and when adopted it takes the place of Section 150 of the Public Health Act, 1875. The procedure of dealing with private streets under this Act is somewhat similar to that under the 1875 Act, but its provisions admit of greater elasticity in the apportionment of expenses between the owners of the land abutting on the street.

PUBLIC HEALTH ACTS AMENDMENT ACT, 1907. This Act is in several Parts, of which all, except Part I, become operative only when adopted by the local authority. Part II of the Act deals with streets and buildings. Section 17 empowers the local authority to vary the position, direction and termination of a proposed new street; under Section 22 the authority may require the corner of any proposed building at the junction of two streets to be rounded or splayed off; in both of these cases compensation is payable to the owner or any other person whose property may be injuriously affected.

ROADS IMPROVEMENT ACT, 1925. Section 5 of this Act provides that a County Council or other highway authority may prescribe, in relation to either side of a highway, a frontage line to which all new buildings must conform. Before prescribing a line the authority must serve notices on all owners and occupiers of land affected, and, when prescribed, the line is to be shown on a map, available for inspection at the offices of the authority. Compensation is payable to any person who can prove that his property is injuriously affected.

PUBLIC HEALTH ACT, 1925. This Act is in several Parts, and Part II which deals with streets and buildings becomes operative only when adopted by the local authority. Section 17 provides that the name of every new street must be approved by the local authority. Section 27 deals with the construction of bridges over streets, under licence from the local authority. Section 31 empowers the local authority to require a proposed new street to be made wider if it will form a main thoroughfare, a main approach, or means of communication between main approaches. If the required width exceeds by more than 20 ft. the maximum by-law width for a new street in the district, compensation is payable. By Section 33 the local authority is empowered to prescribe an improvement line in relation to either side of a narrow street. Such improvement line is to be shown on a plan kept at the offices of the local authority and no new building may be erected in advance of the line, except by consent. Compensation is payable to any person whose property is injuriously affected.

Public Health Act, 1936. While the requirements in regard to streets are still to be found in the Public Health Act, 1875, and its several Amendment Acts, together with the Act of 1925, the requirements in regard to buildings and sanitation are contained in the Public Health Act, 1936, and the by-laws made under such Act. This very extensive Act consists of 347 sections and three schedules. Part II, comprising Sections 14 to 90, deals with sanitation and building work, and these notes are

restricted to the requirements contained in such Part.

SEWERS. Sections 14 to 33 are concerned with sewerage and sewage disposal. Most of these sections deal with works by local authorities, but Sections 25 and 27 affect the carrying out of work by private persons. Section 25 prohibits, except with the consent of the local authority, the erection or extension of a building over a sewer. Section 27 prohibits the passing of petroleum spirit into a sewer or into a drain communicating with a sewer, and prohibits also the passing of any other matter into a sewer or communicating drain which may injure the sewer or drain.

DRAINS. Sections 34 to 42 deal with drains. Under Section 37, when plans of a building or an extension are submitted to a local authority, satisfactory provision for drainage is to be shown; otherwise the authority are empowered to reject the plans, but they can agree to provision for drainage being omitted in any particular case where they are satisfied that it is not necessary. A proposed drain is not satisfactory unless it either connects with a sewer or discharges into a cesspool or "some other place" approved by the local authority. If there is a sewer within 100 ft. of the site of a building, and the owner has a right to construct a drain through the intervening land, then the local authority can insist on the drain being made to connect with the sewer.

PRIVATE SEWERS. The provisions of the Public Health Act, 1875, now repealed, which dealt with the subject of combined drainage, occasioned, because of their uncertainty, many contests in the Courts between local authorities and owners of property. For the decision in a dispute as to whether a particular length of defective pipe was a sewer or combined drain usually determined who was liable for the cost of repair and maintenance.

The provisions of Section 38 of the Act of 1936 have been so worded as to avoid uncertainty and consequent disputes in the case of drainage work for new buildings. The main portion of this section is as follows—

(1) Where a local authority might under the last preceding section require each of two or more buildings to be drained separately into an existing sewer, but it appears to the authority that those buildings may be drained more economically or advantageously in combination, the authority may, when the drains of the buildings are first laid, require that the buildings be drained in combination into the existing sewer by means of a private sewer to be constructed either by the owners of the buildings in such manner as the authority may direct, or, if the authority so elect, by the authority on behalf of the owners:

Provided that a local authority shall not, except by agreement with the owners concerned, exercise the powers conferred by this subsection in respect of any building for the drainage of which plans have been previously passed by them.

(2) A local authority who make such a requirement as aforesaid shall fix the proportions in which the expenses of constructing, and of maintaining and repairing, the private sewer are to be borne by the owners concerned, or, in a case in which the distance of the existing sewer from the site of any of the buildings in question is or exceeds one hundred feet, the proportions in which those expenses are to be borne by the owners concerned and the local authority, and shall forthwith give notice of their decision to each owner affected.

The section goes on to state that a sewer constructed under the section shall not be deemed to be a public sewer by reason of the fact that the expenses of its construction are in the first instance defrayed by the authority, or that some part of the expenses is borne by them. The section concludes by enacting that "so much of any local Act as empowers a local authority to require in certain cases the construction of a combined drain is hereby repealed."

DRAINAGE OF EXISTING BUILDINGS. Sections 39 and 40 deal with buildings having insufficient or defective drainage, or having certain specified defects in the arrangement of soil and other pipes. In any such case the local authority may require the owner to improve the drainage, or to remedy the defect.

SANITARY CONVENIENCES. The provision of sanitary conveniences in both new and existing buildings is dealt with in Sections 43 to 52, and there is further reference to this subject in Sections 88 and 89.

Section 43 empowers a local authority to reject the plans of a proposed building if proper water-closet or earth-closet accommodation is not shown. Section 46, as amended by the Factories Act, 1937, requires every building used as a workplace to be provided with proper sanitary accommodation. The required provision of sanitary accommodation in factories is referred to when dealing with the Factories Act, 1937, in Chapter VIII.

Section 89 deals with the question of sanitary conveniences in certain classes of buildings used by the public. Under this section a local authority may require a reasonable number of sanitary conveniences to be provided by the owner or occupier "of any inn, public-house, beer-house, refreshment-house, or place of public entertain-

ment." As regards the position of public sanitary conveniences erected by private persons, Section 88 provides that no such convenience shall be accessible from a street without the consent of the local authority.

TEMPORARY BUILDINGS, ETC. Section 53 provides that where plans of a building proposed to be constructed of short-lived materials are submitted for approval, the local authority may either reject the plans or approve the building for a limited period. A list of materials liable to rapid deterioration, or otherwise unsuitable for use in permanent construction, may be included in local building by-laws, and a list of this nature is given in By-law 79 of the Model Code, which is dealt with in Chapter V.

Section 54 enables a local authority to reject the plans of a building which is proposed to be erected on ground on which offensive matter has been deposited, unless they are satisfied that the material has been rendered innocuous. Section 58 enables a local authority to require the execution of work for the removal of danger in the case of a building that is dangerous to its occupants or to the occupiers of adjoining buildings. The powers of a local authority under Section 160 of the Public Health Act, 1875, in the case of a building which is dangerous to persons in the street, have already been mentioned.

ENTRANCES AND EXITS IN PUBLIC BUILDINGS. Section 59 provides that where plans of a building or an extension to a building are submitted to a local authority, and the building is one of the kind to which the section applies, the authority shall reject the plans unless they show that the building "will be provided with such means of ingress and egress and passages or gangways as the authority deem satisfactory, regard being had by them to the purposes for which the building is intended to be, or is, used and the number of persons likely to resort thereto at any one time."

The section is stated to apply to—

(a) any theatre, and any hall or other building which is used as a place of public resort;
(b) any restaurant, shop, store or warehouse to which members of the public are admitted and in which more than twenty persons are employed;
(c) any club required to be registered under the provisions of the Licensing (Consolidation) Act, 1910;
(d) any school not exempted from the operation of building byelaws; and
(e) subject as hereinafter provided, any church, chapel or other place of public worship:

The proviso regarding a building used as a church, etc., is to the effect that the section does not apply to a building which was so used before the provisions of Section 35 of the Public Health Acts Amendment Act, 1890, or similar provisions of a local Act, came into force in the district, or, where there were no such provisions in force, to a building which was so used before the commencement of the Act of 1936.

FIRE ESCAPE FROM CERTAIN OTHER BUILDINGS. Under Section 60 if it appears to a local authority "that any building or proposed building which is or will be" a building to which the section applies, and is not or will not be provided with suitable means of escape in case of fire from each storey having a floor more than 20 ft. above the surface of the street or of the adjoining ground, the authority may by notice require the execution of such works as may be necessary. It will be seen that both existing buildings and proposed new buildings may be dealt with under the section. The section is stated to apply to the following buildings—

Any building which exceeds two storeys in height and in which the floor of any upper storey is more than 20 feet above the surface of the street or ground on any side of the building, and which—
(a) is let in flats or tenement dwellings; or
(b) is used as an inn, hotel, boarding house, hospital, nursing home, boarding school, children's home or similar institution; or
(c) is used as a restaurant, shop, store or warehouse and has on any upper floor sleeping accommodation for persons employed on the premises.

The 20 ft. height limitation will result in some three storey buildings, by reason of deeply sunk basements and low storey heights, being excluded from the operation of the section, but most buildings of more than two storeys, if of the classes mentioned, will be subject to its provisions.

BY-LAWS. Sections 61 to 69 deal with the making and administration of by-laws. Section 61 provides that every local authority may, and, if required by the Minister of Health, shall make by-laws in respect of a list of matters mentioned in the sections. By Section 250 of the Local Government Act, 1933, all by-laws must be confirmed by the Minister of Health before they are effective.

RELAXATION OF BY-LAWS. Section 63 provides that a local authority may, with the consent of the Minister, relax any by-law of which they consider the operation would be unreasonable in any particular case. Notice of any proposed relaxation is to be given in such manner and to such persons as the Minister may direct, and

the Minister is to take into consideration any objections received.

REFERENCE TO MINISTER. Section 67 deals with the question of a disagreement between an authority and an owner of a building. The section is as follows—

If any question arises between a local authority and a person who has executed, or proposes to execute, any work—

(a) as to the application to that work of any building byelaws; or

(b) whether the plans of the work are in conformity with those byelaws; or

(c) whether the work has been executed in accordance with the plans as passed by the authority,

the question may, on an application made jointly by him and the local authority, be referred to the Minister for determination, and the Minister's decision shall be final:

Provided that the Minister may at any stage of the proceedings on the reference and shall, if so directed by the High Court, state in the form of a special case for the opinion of the High Court any question of law arising in those proceedings.

LIMIT OF TIME FOR BY-LAWS. Section 68 puts a limit of time on the unmodified existence of a set of by-laws. An opportunity is thus given, at periodic intervals, for reconsidering and modifying, if necessary, any by-law which may be thought to have hindered the development of desirable methods of construction. The text of the section is as follows—

Subject as hereinafter provided—

(a) any building byelaw made by a local authority under this Part of this Act shall cease to have effect on the expiration of ten years from the date on which it was made;

(b) any building byelaw made by a local authority under the corresponding provisions of any enactment repealed by this Act, or under any such enactment as amended or extended by a local Act, shall cease to have effect on the expiration of three years from the passing of this Act:

Provided that the Minister may by order extend the period during which any byelaw mentioned in this section is to remain in force.

EXEMPTIONS FROM BY-LAWS. The following classes of buildings are stated by Section 71 to be exempt from building by-laws—

(a) any buildings, being school premises, erected or to be erected according to plans which are under any regulations relating to the payment of grants required to be, and have been, approved by the Board of Education; or

(b) any buildings constructed by a county council or local authority in accordance with plans approved by the Minister of Agriculture and Fisheries under the Small Holdings and Allotments Acts, 1908 to 1931, or any Act amending those Acts or any of them; or

(c) any buildings belonging to any statutory undertakers and held or used by them for the purposes of their undertaking:

By "statutory undertakers" is meant such bodies as railway companies, gas companies, dock and canal companies, which function under Acts of Parliament. The exemption of buildings of these bodies is stated in the section "not to extend to houses, or to buildings used as offices or showrooms, other than buildings so used which form part of a railway station."

In addition to the above-mentioned list of exempted buildings, each local set of by-laws will be found to contain a list of classes of buildings either wholly or partly exempt, such list being based on the list of exempted buildings in the Model By-laws, referred to in Chapter V.

DEFINITION OF "ERECTION OF BUILDING." As many requirements both of the Act and by-laws have reference only to new buildings it is important to know what constitutes the erection of a building. This is dealt with in Section 90 for the purposes of Part II of the Act as follows—

(2) For the purposes of this Part of this Act and, so far as byelaws made thereunder may provide, for the purposes of those byelaws, any of the following operations shall be deemed to be the erection of a building, that is to say—

(i) The re-erection of any building or part of a building when an outer wall of that building or, as the case may be, that part of a building has been pulled down, or burnt down, to within ten feet of the surface of the ground adjoining the lowest storey of the building or of that part of the building;

(ii) the re-erection of any frame building or part of a frame building when that building or part of a building has been so far pulled down, or burnt down, as to leave only the framework of the lowest storey of the building or of that part of the building;

(iii) the roofing over of any open space between walls or buildings;

and the word "erect" shall be construed accordingly.

RIGHTS OF APPEAL. In a large number of cases under the Act of 1936 there is the right of appeal from the decision or requirement of the local authority to "a court of summary jurisdiction," which is the local petty sessional court, of unpaid magistrates in most districts, and of a stipendiary magistrate in a few large towns. In the case of matters under Sections 35 and 37, as an alternative to appeal, there is the right to require the matter in dispute to be referred to arbitration. Appeals and references to arbitration are regulated by Sections 300 to 303. An appeal must be made within 21 days of the date of receipt of the decision or requirement of the local authority. Except in those cases where there is a right of arbitration, any person aggrieved by a decision of a court of summary jurisdiction may appeal to quarter sessions.

Chapter V—MODEL BY-LAWS

It has already been stated that the by-laws concerning new streets, building work and sanitation differ for each district, but are all based on certain Model Codes. A summary of the most important requirements of the Model Codes issued for England and Wales by the Ministry of Health will now be given. But it must be appreciated that only a summary is given, and that these requirements do not exactly apply in any district. Persons concerned with the erection of buildings in any particular district should obtain a copy of the local by-laws, which are usually supplied either free or at a small charge at the local council offices.

At one time there were three Codes, each dealing with streets and buildings, one Code for urban districts, one for rural districts and an intermediate Code for districts of semi-rural character. In 1937–1938, these three Codes were replaced by two Codes applicable to all districts, one dealing with new streets, and the other, a much more extensive one, dealing with buildings.

Code for New Streets. Streets are required to be laid out to the easiest practicable gradients and of a width which is regulated by their length and by the distance of existing buildings, if any, from the middle of the street. The requirements of the Code as regards the width of a street used as a carriage-road are as follows:

3. A person who shall lay out for use as a carriage-road a new street intended to be the principal means of access to any building shall lay out the street of the width of *thirty-six feet* at the least:

Provided that the street shall not be required to be laid out of a greater width than—

(1) *thirty feet*, if—

(*a*) the street does not exceed *one thousand feet* in length; and

(*b*) every main wall of any building in the street is distant not less than *thirty feet* from the middle of the street;

(2) *twenty-four feet*, if—

(*a*) the street does not exceed *three hundred feet* in length; and

(*b*) every main wall of any building in the street is distant not less than *twenty-five feet* from the middle of the street;

(3) *twenty-six feet*, if—

(*a*) the street does not exceed *one thousand feet* in length; and

(*b*) every main wall of any building in the street is distant not less than *thirty feet* from the middle of the street; and

(*c*) there are domestic buildings only in the street; and

(*d*) either—

(i) the erection of buildings on one side of the street is impracticable or prohibited by reason of a canal, river or railway, or of the configuration of the ground, or of the permanent appropriation of the land as a recreation ground or as gardens; or

(ii) any buildings erected in the street are on one side only and at the time the street is laid out the land on both sides of the street is in the same ownership;

(4) *twenty-one feet*, if—

(*a*) the street does not exceed *three hundred feet* in length; and

(*b*) every main wall of any building in the street is distant not less than *twenty-five feet* from the middle of the street; and

(*c*) there are domestic buildings only in the street; and

(*d*) either—

(i) the erection of buildings on one side of the street is impracticable or prohibited by reason of a canal, river or railway, or of the configuration of the ground, or of the permanent appropriation of the land as a recreation ground or as gardens; or

(ii) any buildings erected in the street are on one side only and at the time the street is laid out the land on both sides of the street is in the same ownership.

The width of the carriage-way is required to be not less than 24 ft. for a street 36 ft. wide, not less than 20 ft. for a street 30 ft. or 26 ft. wide, and not less than 15 ft. for a street 24 ft. or 21 ft. wide. Minimum widths of foot-way, depending on the width of the street, are also laid down.

The Code contains the general rule that a street intended to be the principal means of access to any building shall be laid out for use as a carriage-road. But under certain prescribed conditions a street forming the principal means of access to a building may be laid out for foot-traffic only.

It is important to appreciate that, in addition to the foregoing rules, local authorities have extensive powers in regard to new streets under the Town and Country Planning Acts, which are dealt with in Chapter VIII.

The required cross fall of a carriage-way of a street, from the crown of the road to the kerb,

is stated in the Code to be not less than ¼ in. and not more than ¾ in. to the foot; that of a foot-way is stated to be not less than ½ in. and not more than ¾ in. if unpaved, and not less than ¼ in. and not more than ½ in. if paved. Proper arrangements are to be made for carrying off the surface water. The height of a kerb above the adjoining channel is stated to be not less than 3 in. and not more than 7 in.

The plans to be submitted to a local authority for the formation of a new street comprise a plan, a longitudinal section and cross-sections.

Code for Buildings. While it will be found that the by-laws in most districts are in general conformity with the Code, certain differences will sometimes be encountered, and, in the larger towns, by-laws to which there are no equivalents in the Code will often be found to be in force. This is particularly so in the case of timber construction. References to timber in the Code are in general terms only, whereas the by-laws of many districts contain detailed requirements regarding the construction of timber floors and roofs.

DEFINITIONS. Before dealing with the detailed requirements of the Code it will be desirable to give the principal definitions; these are as follows—

"base," applied to a wall, means the under side of that part of the wall which immediately rests upon the footings or foundation or upon any bressummer or other structure by which such wall is carried;

"bressummer" means a beam or girder which carries a wall;

"building of the warehouse class" means a warehouse or factory;

"dead load" means the weight of all walls, floors, roofs, partitions and other like permanent construction;

"domestic building" means a dwelling-house, shop, office building or any other building which is neither a public building nor a building of the warehouse class;

"external wall" means an outer wall of a building not being a party wall, even though adjoining a wall of another building;

"height," applied to a building, means the height of the building measured from the mean level of the ground adjoining the outside of the external walls to the level of *half* the vertical height of the roof, or to the top of the walls or of the parapet, if any, whichever is the higher;

"mortar" means cement mortar, cement-lime mortar, lime mortar or black mortar;

"party wall" means—

(1) a wall forming part of a building and used or constructed to be used for separation of adjoining buildings belonging to different owners, or occupied or constructed or adapted to be occupied by different persons; or

(2) a wall forming part of a building and standing, to a greater extent than the projection of the footings, on lands of different owners;

"public building" means a building used or constructed or adapted to be used, either ordinarily or occasionally, as a church, chapel or other place of public worship, or as a hospital, public institution, college or school (not being merely a dwelling-house so used), theatre, public hall, public concert room, public ballroom, public lecture room or public exhibition room, or as a public place of assembly for persons admitted thereto, by tickets or otherwise, or used or constructed or adapted to be used, either ordinarily or occasionally, for any other public purpose;

"slenderness ratio," applied to a wall, means the number resulting from dividing the height of the wall by its least overall thickness, and for this purpose the height shall be the clear distance between lateral supports;

"slop sink" means a sink intended for receiving solid or liquid filth;

"superimposed load" means all loads other than the dead load

EXEMPTIONS. Certain buildings are stated to be wholly, conditionally, or partially exempt from the by-laws, and to understand the exemptions it is necessary to see how the Code is made up. It consists of four parts, namely Part I: Introductory, dealing principally with definitions and exemptions; Part II: Buildings, containing the main building requirements; Part III: Works and Fittings, including all requirements as to drainage and sanitation; Part IV: Miscellaneous, containing the requirements as to the giving of notices and the submission of plans to the local authority. In Part II there is a by-law, No. 79, which deals with the use of short-lived materials, and is linked with the provisions of Section 53 of the Public Health Act, 1936, already referred to in Chapter IV.

The provisions of the Code as to the entire exemption of certain buildings are as follows—

3. The following buildings shall be exempt from the operation of these byelaws:—

(1) a building (not being a dwelling-house) erected in connection with any mine, and used or to be used exclusively for working of the mine;

(2) a moveable dwelling to which section 269 of the Public Health Act, 1936, applies;

(3) a building constructed to be used exclusively for the accommodation of hop-pickers and other persons engaged temporarily in picking, gathering or lifting fruit, flowers, bulbs, roots or vegetables.

It should be realized that this list of wholly exempted buildings is only a subsidiary one, the main list of buildings wholly exempt from building by-laws being that given in Section 71 of the Public Health Act, 1936, already quoted in Chapter IV.

The Code gives in by-laws 4 and 5 the following extensive list of conditionally exempted buildings—

4. The following byelaws, except byelaw 122 so far as it requires notice to be given of the intention to erect buildings, the submission of written particulars and notice of a material change of user, shall not apply to—

(1) a building constructed to be used exclusively as a poultry-house or aviary, if it is wholly detached and distant not less than *ten feet* from every building other than a building specified in this byelaw or in byelaws 5 or 6;

(2) a building constructed to be used exclusively as a plant-house, greenhouse, conservatory, orchard-house, summer-house, boat-house not intended for the accommodation of a motor boat, coal-shed, garden tool-house, potting shed or cycle-shed, if it is either—

(*a*) not more than *one thousand cubic feet* in capacity; or

(*b*) wholly detached and distant not less than *ten feet* from every building other than a building specified in this byelaw or in byelaws 5 or 6;

(3) a building constructed to be used only in connection with and during the construction, alteration or repair of any building or other work.

5. The following byelaws, except byelaw 79 (as to short-lived materials) and byelaw 122 so far as it requires notice to be given of intention to erect buildings, the submission of written particulars, the delivery of plans, and notice of a material change of user, shall not apply to --

(1) a building constructed to be used exclusively as a motor garage or boat-house intended for the accommodation of a motor boat, if it does not exceed *three hundred square feet* in floor area and either—

(*a*) the walls and floor (if any) are constructed of incombustible material, and the roof is constructed of or externally covered or internally lined with fire-resisting material; or

(*b*) it is not fitted with any form of heating apparatus designed or adapted for the combustion of fuel or gas within the building, and is wholly detached and distant not less than *ten feet* from every building other than a building specified in this byelaw or in byelaws 4 or 6, and (where the walls and roof are not constructed of or externally covered or internally lined with fire-resisting material) from the nearest boundary of any adjoining lands or premises;

(2) a building which is not a public building, and is not constructed to be used either wholly or partly for human habitation, or as a place of habitual employment for any person in any manufacture, trade or business, if it—

(*a*) does not exceed in height *thirty feet* and does not exceed in capacity *one hundred and twenty-five thousand cubic feet*, and is distant not less than *eight feet* from any street, and not less than *thirty feet* from any building other than a building exempt under this byelaw or byelaws 4 or 6, and from the nearest boundary of any adjoining lands or premises;

(*b*) exceeds either in height or capacity, but not in both, the figures specified in the last sub-paragraph, and is distant not less than *twenty feet* from any street, and not less than *fifty feet* from any building other than a building exempt under this byelaw or byelaws 4 or 6, and from the nearest boundary of any adjoining lands or premises;

(*c*) exceeds both in height and capacity the figures specified in sub-paragraph (*a*) of this paragraph, and is distant not less than *thirty feet* from any street, and not less than *sixty feet* from any building other than a building exempt under this byelaw or byelaws 4 or 6, and from the nearest boundary of any adjoining lands or premises.

By-law 6 gives a short list of buildings which are partly exempt, subject to certain conditions—

6. Part II of these byelaws, except byelaw 79 (as to short-lived materials), shall not apply to—

(1) a building constructed to be used by day only for private occupation and not for any trade or business, which does not exceed *one thousand cubic feet* in capacity;

(2) a building constructed to be used, for a limited period only, in connection with the sale or letting of buildings or building plots in the course of the development of an estate and erected on or in close proximity to the estate.

By-law 7, which completes the exemptions, states that certain one-storey buildings, not used for human habitation, and complying with a list of conditions, are exempt from certain by-laws, but not, it should be noted, from the by-laws dealing with drainage and sanitation; the by-law runs as follows—

7. The byelaws with respect to sites, foundations and walls shall not apply to a building which is not constructed to be used either wholly or partly for human habitation if—

(1) the building comprises not more than *one* storey; and

(2) the height of the building does not exceed *thirty feet*; and

(3) the capacity of the building does not exceed *eighty thousand cubic feet*; and

(4) the external walls rest on a suitable and sufficient foundation; and

(5) the external walls are so constructed as to provide a suitable degree of fire-resistance; and

(6) the external walls are constructed of sufficient strength to secure due stability; and

(7) the building is distant from the boundary of any adjoining lands or premises (not being a street) not less than—

(*a*) *ten feet*, where it does not exceed *two thousand cubic feet* in capacity;

(*b*) *fifteen feet*, where it exceeds *two thousand cubic feet* but does not exceed *fifteen thousand cubic feet* in capacity;

(*c*) *thirty feet*, where it exceeds *fifteen thousand cubic feet* in capacity.

MATERIALS. The requirements of the Code as to building materials are based on good modern practice and are given in considerable detail in by-laws 8 to 18. Bricks and blocks used in walling are to be composed of hard well-burned clay or terra-cotta, natural or cast

stone, concrete, calcium-silicate, or other incombustible material of like hardness and durability. Those of calcium-silicate, commonly termed "sand-lime bricks" are to be in compliance with Class A of British Standard Specification No. 187—1934. Cement is to be either Portland Blast Furnace or High Alumina cement, complying in each case with the respective British Standard Specification, or any other cement not inferior in quality.

The requirements regarding sand and water are as follows—

10. Sand used for mortar shall be clean, well-graded, and substantially free from pebbles and large particles and material which will pass through a No. 100 British Standard sieve, and shall consist of—

(1) hard natural sand containing not more than *six per cent.* of loam or clay; or
(2) crushed hard rock; or
(3) crushed brick free from old plaster; or
(4) crushed hard furnace clinker free from dust; or
(5) other not less suitable material.

11. Water shall be clean and free from deleterious matter.

Mortar may be either cement mortar, cement-lime mortar, lime mortar, or black mortar; the detailed requirements are as follows—

12.—(1) Cement mortar shall be composed of cement and sand in the proportion of *one part* of cement to not less than *two* nor more than *four parts* of sand measured by volume of the materials when dry.

(2) Cement-lime mortar shall be composed of Portland cement or Portland-Blastfurnace cement, and either high calcium lime or true moderately hydraulic lime (either in the form of properly slaked lime putty of normal consistence or sound dry hydrate), and sand. The proportion of cement to lime shall be *one part* of cement to not less than *one* nor more than *three parts* of lime measured by volume of dry cement, dry hydrate or lime putty respectively: the proportion of the mixture of cement and lime to sand shall be *one part* of the mixture to not less than *two* nor more than *four parts* of sand measured by volume.

(3) Lime mortar shall be composed of sand and either—

(*a*) high calcium lime, used either as putty of normal consistence from sound hydrated lime or as sound matured putty of normal consistence from properly run quicklime, in the proportion of *one part* of putty to not less than *two* nor more than *four parts* of sand measured by volume; or

(*b*) magnesian lime, properly slaked, in the proportion of *one part* of lump quicklime to not less than *two* nor more than *three parts* of sand, measured by volume; or

(*c*) true moderately hydraulic lime, used as sound dry hydrated lime or properly slaked quicklime, in the proportion of *one part* of hydrated lime or slaked quicklime to not less than *two* nor more than *four parts* of sand, measured by volume; or

(*d*) eminently hydraulic (lias) lime, properly slaked, in the proportion of *one part* of lime to not less than *two* nor more than *four parts* of sand, measured by volume of the materials when dry.

(4) Black mortar shall consist of high calcium lime or hydraulic lime and a filler consisting of clean furnace clinkers reasonably free from unburnt coal, soot or flue refuse, with or without sand. The lime shall be used either as sound dry hydrated lime run to putty of normal consistence, or as properly slaked quicklime run to sound putty of normal consistence, or as fresh quicklime. The lime shall be thoroughly and finely ground with the filler and with water in a suitable mill. The mortar shall be composed of *one part* of lime putty to not less than *two* nor more than *four parts* of the filler measured by volume, or *one part* of fresh quicklime to not less than *four* nor more than *eight parts* of the filler measured by volume.

Aggregates for concrete are required to be properly graded and are to contain no coal or coal residues, such as clinker, ashes, coke-breeze, pan-breeze or slag, or other materials, in so far as any such materials are liable to reduce the strength or durability of the concrete, or to attack the reinforcement in the case of reinforced concrete.

The proportioning of concrete is required to be as follows—

(*a*) for all load-bearing members in reinforced concrete and for the protective encasement of structural steel and reinforced concrete members—not less than *one hundred and twelve pounds* of cement to every *two-and-a-half cubic feet* of fine aggregate and *five cubic feet* of coarse aggregate, or such proportion of fine aggregate to coarse aggregate as will produce a concrete of a compressive strength not less than *three thousand three hundred and seventy-five pounds per square inch* when tested in accordance with the standard method of making preliminary cube tests of concrete set out in Appendix VII to the Report of the Reinforced Concrete Structures Committee of the Building Research Board, dated July, 1933;

(*b*) for covering the site of a building—not less than *one hundred and twelve pounds* of cement to every *three-and-a-half cubic feet* of fine aggregate and *seven cubic feet* of coarse aggregate;

(*c*) for foundations, the support or protection of drains, and similar purposes—not less than *one hundred and twelve pounds* of cement to every *fifteen cubic feet* of coarse and fine aggregate in combination.

If the weight of cement be taken at 90 lb. per cubic foot, it will be seen that the foregoing mixes are equivalent to the following proportions in terms of volume in the case of both cement and aggregate:— (*a*) 1 : 2 : 4, (*b*) 1 : 3 : 6, (*c*) 1 : 12.

As regards the other main building materials, there are certain specific requirements in the case of steel and timber. Steel in reinforced concrete is to comply with British Standard Specification No. 785—1938, and expanded metal is to conform with British Standard

Specification No. 405—1930. Other steel is to be not inferior in strength and suitability to British Standard Specification No. 15—1936, for structural steel. Timber is to be of a quality and strength sufficient for its purpose; it is to be well seasoned, sound, free from rot, worm, beetle and vermin, and is not to contain large, loose or dead knots, splits or other defects to such an extent and so situated in the piece as to render it insufficient in strength or stiffness.

SITES OF BUILDINGS. The Code requires the ground surface underneath a domestic building, unless the exceptional condition of the site or soil renders it unnecessary, to be covered with either asphalt, a 6 in. layer of spade-finished cement concrete, a 4 in. layer of similar concrete on a bed of clinker or broken brick, or the surface covered with some not less suitable material. The Code also contains requirements in regard to the drainage of the subsoil of a building where the dampness of the site renders this necessary, and the raising of the sites or lowest floors of buildings situated on low-lying land.

FOUNDATIONS. The subject of foundations for structural walls is dealt with in the Code by first giving the requirements of a proper foundation, then particulars of various types of foundation, and then a description of the width and thickness necessary for foundations of ordinary domestic buildings on certain subsoils of fairly good bearing capacity. The requirements of a proper foundation are—

22. The foundations of every building shall be—

(1) so constructed as to sustain the combined dead load of the building and the superimposed load and to transmit those loads to the subsoil in such a manner that the pressure on the subsoil shall not cause such settlement of the building or any part of the building as may impair its stability; and

(2) taken down to such a depth or so constructed as to render the building immune from damage from movements due to seasonal variation in the content of moisture in the ground.

Foundations of structural walls are to consist either of cement concrete, or of footings, or of a combination of footings and cement or lime concrete; alternatively they may be constructed as a raft or as a piled foundation. Where a wall rests on solid undisturbed rock it need not have a foundation, and a wall may of course rest direct on a bressummer.

Where a wall of a domestic building is not more than 50 ft. high and the bearing capacity of the ground under its foundation is not inferior to that of firm clay or coarse sand the requirements of the Code are deemed to be satisfied if the width of the bottom of the foundation is not less than 12 in., or twice the thickness of the wall in the lowest storey (whichever is the greater) and the thickness of the foundation is not less than 9 in. or not less then 1⅓rd times the projection of the foundation from the base (whichever is the greater).

CONSTRUCTION OF WALLS. The requirements in regard to the construction of walls, which occupy fifteen pages of the official copy of the Code, are not very easily summarized. The method here adopted is that of dealing first with the rules for normal brick-enclosed buildings, and then continuing with those of less usual construction; this, it will be seen, has involved a departure from the sequence of the by-laws in the Code.

The rules for normal brick-enclosed buildings are given in by-laws 31, 38, 39, 40, and 44. The walls of such buildings are to be constructed of bricks or blocks properly bonded and solidly put together with mortar, or other good, hard and suitable incombustible material properly and solidly put together. External and party walls are to be of a tabulated thickness, regulated by their height and their length measured between the centres of return walls, there being one table for domestic buildings and another for public buildings and buildings of the warehouse class. A cross wall when considered as a return wall for the purpose of determining the length of an external or party wall is to be two-thirds the tabulated thickness and in no case less than 8½ in. All local by-laws contain two tables of wall thickness, following in most cases the tables in the Code; reliance, however, should not be placed on the Code tables, but the local by-law tables should be consulted in the case of proposed building work in any particular district.

HOLLOW WALLS. These are, of course, permissible and are now frequently adopted in the case of domestic buildings in positions exposed to the weather. The Code rules for hollow walls are as follows—

34. Where any wall or any part of a wall is constructed as a hollow wall—

(1) the cavity between the inner and outer parts of the wall shall throughout be of a width not exceeding *three inches*;

(2) the inner and outer parts of the wall shall be securely tied together with suitable bonding ties of adequate strength formed of galvanized iron, iron tarred and sanded, glazed stoneware, copper, bronze or other not less suitable material, the ties

being placed at distances apart not exceeding *three feet* horizontally and *eighteen inches* vertically;

(3) the inner and outer parts of the wall shall each be not less than *four inches* thick throughout, except that in a wall not exceeding *twenty-five feet* in length and *twenty feet* in height the thickness of each part may be not less than *three inches* throughout if all courses of less height than *six inches* are put together with cement mortar or with cement-lime mortar of the strongest mixture prescribed by the byelaw in that behalf or the wall has at least *twice* the number of ties required by the preceding paragraph;

(4) the cavity may be reckoned as part of the thickness prescribed for walls by these byelaws where such thickness does not exceed *eight-and-a-half inches* but shall not be so reckoned where such thickness exceeds *eight-and-a-half* inches

35. Where a wall or part of a wall is constructed as a hollow wall or with hollow blocks, all woodwork inserted in the wall so as to project into or extend across a cavity shall be effectually protected on the upper side with a layer of sheet lead or other equally suitable material impervious to moisture.

STEEL FRAME AND REINFORCED CONCRETE CONSTRUCTION. The previous Code dealt with steel-frame and reinforced concrete construction by exempting these forms of construction from the by-laws, subject to certain conditions as to the strength of the framework and as to the construction of party walls and the panels of external walls. The present Code contains detailed requirements as to the construction of walls with a structural framework of steel or reinforced concrete. These requirements, being comparatively new, are not very well known, and are given in full as follows—

29.—(1) Every part of a wall with a structural framework of steel, iron or reinforced concrete shall be so constructed that—

(*a*) the wall shall be capable of safely sustaining and transmitting the dead loading and the superimposed loading to which it may be subjected calculated in accordance with the First Schedule to these byelaws so far as it is applicable, and the horizontal and inclined forces to which it may be subjected, without undue settlement or deflection and without exceeding the appropriate limits of stress for the materials of which it is constructed;

(*b*) the wall shall be durable;

(*c*) the wall shall possess a degree of fire-resistance appropriate to the purpose for which the building is intended to be used;

(*d*) the spaces of the framework shall be filled with panels of, or externally covered with, hard and incombustible material, which shall be properly secured to the framework and, where the wall is an external wall, be reasonably weatherproof.

(2) Where the framework is of steel, the requirements of this byelaw, so far as it relates to framework, shall be deemed to be satisfied—

(*a*) as regards structural stability, if every element of the framework is designed in accordance with the rules set out in British Standard Specification No. 449—1937 for the Use of Structural Steel in Building;

(*b*) as regards durability, if the framework is protected against corrosion by a sufficient encasement of concrete or by a suitable coating of paint or bitumen;

(*c*) as regards fire-resistance, in the case of a domestic building the uppermost floor of which is not more than *forty feet* above the adjoining ground, if the framework is encased in one of the following materials of the thickness specified below, except at rivet heads, angle cleats, plate covers and similar places, and, except where otherwise provided, all re-entrant spaces are filled with concrete or other not less suitable material properly bonded or tied into the encasement:—

concrete, of the quality specified for the protective encasement of structural steel in the byelaws with respect to materials, not less than *one-and-a-half inches* thick;

solid bricks of clay or calcium silicate or solid precast concrete blocks, in which the courses are properly bonded and secured, not less than *two inches* thick;

suitable hollow blocks of clay or concrete properly bonded, anchored or tied, not less than *two inches* thick;

suitable hollow gypsum tiles, properly bonded, anchored or tied, not less than *two inches* thick;

solid gypsum tiles, properly bonded, anchored or tied, not less than *one inch* thick;

Portland cement rendering or gypsum plaster, on a suitable metallic mesh, not less than *one inch* thick, the re-entrant spaces not being filled.

(3) Where the framework is of reinforced concrete, the requirements of this byelaw, so far as it relates to framework, shall be deemed to be satisfied, as regards structural stability and durability, if every element of the framework is designed in accordance with the rules set out in the Report of the Reinforced Concrete Structures Committee of the Building Research Board, dated July, 1933.

(4) The requirements of this byelaw, so far as it relates to the panels in any external wall of a domestic building, shall be deemed to be satisfied, in the case of single-leaf panels, if the panels are not less than *eight-and-a-half inches* thick exclusive of any plaster, and are constructed of solid or hollow bricks or blocks of clay, concrete, calcium silicate, natural stone or cast stone, or a combination of any of those materials securely bonded or tied together.

It will have been seen in paragraph 1 (*a*) of by-law 29, that walls of steel and reinforced concrete framed construction are to be capable of safely sustaining loads calculated in accordance with the 1st Schedule of the Code. This schedule of loading is very similar to that applying in London, which is given in Chapter VII.

CALCULATED BRICK AND MASONRY CONSTRUCTION. By-law 37, provides that, except in the case of private dwelling-houses, it is permissible to erect a building with brick or masonry enclosures without conforming with the ordinary schedule of wall thicknesses, but in accordance with calculations based, as

regards loading, on the 1st Schedule, and, as regards the strength of the walls, on tables of permissible pressures given in the 2nd Schedule. These pressures vary according to the strength of the particular brick or block employed, and that of the mortar of the joints, and are reduced by a percentage in accordance with the slenderness ratio of each wall.

SPECIAL TYPES OF WALLS. The remaining by-laws in the Code which concern wall-construction deal with the less common forms, including timber-framing filled with incombustible material, walls of reinforced brickwork, and walls formed of materials such as rubble stone, or clunches of brick, not laid in horizontal beds or courses.

DAMP-PROOF COURSES. By-law 36 requires that every wall and pier of a public building or a domestic building shall be provided with a damp-proof course at a height of not less than 6 in. above the surface of the adjoining ground, beneath the level of the underside of the lowest floor timbers in the case of an open-joist floor, and not higher than the upper surface of the concrete in the case of a solid floor. In the by-laws of some districts it may be found that the walls of factory and warehouse buildings are also required to have a damp-proof course. By-law 36 deals also with the case where the lowest storey of a building extends below the ground, and is not used merely for storage purposes; in such a case the walls in contact with the ground must be constructed so as to be impervious to moisture or as hollow walls.

The materials suitable for damp-proof courses are given in By-law 14, where, in addition to the usual well tried materials, slates in cement, lead, copper and asphalt, there is a reference to engineering bricks of a certain degree of impermeability, and to bituminous materials, other than asphalt, conforming to British Standard Specification No. 743—1937.

RECESSES AND CHASES. By-laws 46 and 47 deal with recesses and chases in external and party walls. The rules of By-law 46 in regard to recesses are as follows—

(1) the wall at the back of the recess shall be not less than *eight-and-a-half inches* thick;
(2) a sufficient arch or lintel of incombustible material shall be built in every storey over the recess;
(3) in each storey the aggregate extent of recesses causing the wall at the back to be of less thickness than that prescribed by these byelaws shall not exceed *one-half* of the superficial extent of the wall;
(4) that side of the recess which is the nearer to the inner face of a return external wall shall be distant not less than *thirteen inches* therefrom.

By-law 47 requires that a chase shall:—

(1) be not less than *seven feet* from every other chase on the same side of the wall;
(2) be not less than *thirteen inches* from any other chase and from any return wall;
(3) be not more than *fourteen inches* wide;
(4) be not more than *four-and-a-half inches* deep from the face of the wall;
(5) leave the wall at the back not less than *eight-and-a-half* inches thick.

OPENINGS IN EXTERNAL WALLS. By-law 48 requires that, when in an external wall an opening is left of a greater extent than one-half of the vertical elevation of the storey or storeys in which the opening is formed, sufficient supports having a suitable degree of fire-resistance are to be provided.

BRESSUMMERS. By-law 49 requires that every bressummer shall—

(1) be borne by a sufficient template of stone, iron, terracotta, vitrified stoneware or other not less suitable material, of at least the full breadth of the bressummer, and shall have a bearing in the direction of its length of not less than *four inches* at each end; and
(2) where necessary, have such storey posts, iron columns, stanchions or piers, of brick, stone or other not less suitable material, on a solid foundation sufficient to carry the superstructure.

COPINGS. By-law 52 requires that where a wall of a public building or a domestic building is carried up as a parapet, it shall have a proper coping. In some districts it may be found that this requirement extends also to the walls of buildings of the warehouse class.

SPECIAL REQUIREMENTS AS TO PARTY WALLS. By-law 53 provides that where a wall is a party wall—

(1) it shall be carried up at least as high as the underside of the slates or other covering of the roof;
(2) if the wall is not carried up above the underside of the slates or other covering, the slates or other covering shall where practicable be properly and solidly bedded in mortar on the top of the wall;
(3) no opening shall be made or left in the wall;
(4) the end of every wooden bressummer, beam, joist, purlin or plate, and of all bond timber, placed in the wall—
  (*a*) shall not extend beyond the middle of the wall; and
  (*b*) shall be properly encased in either brickwork or other solid and incombustible material, not less than *four inches* thick, or an iron beam box with a solid back;
(5) no timber or woodwork forming part of the roof of the building, except laths and slate battens properly embedded in mortar or other not less suitable incombustible material, shall extend upon or across the wall.

CHIMNEYS, FLUES AND HEARTHS. These are dealt with at considerable length in By-laws 54 to 76, but it is provided that the requirements of the Code are not to apply—

(1) to any chimney shaft for the furnace of a steam

boiler, engine, brewery, distillery or manufactory, or any duct or pipe in connection therewith if the duct or pipe is properly constructed of good, hard and incombustible material and is so arranged as to avoid the risk of fire;

(2) to any chimney which is so constructed as not to be capable of use except in connection with a fire or stove which burns gas only, or to any chimney which does not form part of the structure of a building, if the chimney is constructed of incombustible material of sufficient thickness and suitably insulated from any floor, wall or roof through which it passes, and if suitable provision is made effectually to prevent the flames of the fire or stove from coming into contact with the floor of the room in which it is situated.

The requirements of the Code in regard to chimney and flues are rules of good practice, dealing with the construction of the jambs, back and head of fire-place openings, specifying the minimum thickness of material surrounding flues, the minimum and maximum height of chimney stacks, the minimum distance of woodwork from flues, and other similar matters. In many cases the requirements are the same as those of the London Building By-laws which are dealt with in Chapter VII. The requirements of the Code in regard to hearths are as follows—

75. A hearth shall be constructed in connection with every fireplace opening and shall—

(1) be fixed under and in front of the opening;

(2) be properly constructed of stone, slate, bricks, tiles or other incombustible material properly and securely supported;

(3) be not less than *six inches* thick;

(4) extend not less than *six inches* at each end beyond the opening;

(5) project not less than *sixteen inches* from the chimney breast;

(6) be so laid that its upper surface is not lower than the floor of the room in which the opening is situated.

76. Timber or woodwork shall not be placed under a fireplace opening within *ten inches* of the upper surface of the hearth.

DAMP PROTECTION OF SOLID FLOORS. By-law 77 states that every wooden floor laid direct on concrete resting on the ground is to be protected from dampness or dry rot. Except where there is water pressure under the floor, this requirement is deemed to be satisfied if—

(*a*) the boards, planks or wood blocks are laid or bedded upon a continuous layer, not less than *one-eighth-of-an-inch* thick, of bitumen of a suitable grade or coal tar pitch, which is carried up against the walls adjoining the floor to the level of the upper surface of the floor; and

(*b*) where the boards or planks are nailed to wooden fillets embedded in concrete, the fillets are thoroughly impregnated with creosote.

ROOF COVERINGS. By-law 78 requires that the roof of a building shall be weathertight, and also that, except where the building is distant not less than twice its height from the nearest boundary of its site, and from any other building, the roof shall be covered with one or other of certain specified materials. These are—

(*a*) natural or asbestos cement slates;

(*b*) tiles or slabs of burnt clay, concrete, stone, glass or asbestos cement;

(*c*) lead, copper or zinc;

(*d*) asphalte mastic (containing not less than *eighty-three per cent* of mineral matter) not less than *three-quarters-of-an-inch* thick laid on boards of a finished thickness not less than *one inch* or on a base of concrete or hollow tiles;

(*e*) built-up material of a total thickness of not less than *three-tenths-of-an-inch* composed of not less than *three* layers of bituminous felt laid in bituminous mastic on a base of concrete or hollow tiles;

(*f*) asbestos cement sheeting, wired glass sheeting, iron or steel sheeting well galvanised and of a thickness not less than that known as No. 24 Birmingham Wire Gauge, or protected metal sheeting of a not less thickness of metal;

(*g*) bituminous material laid on a base of boards, concrete or hollow blocks, and covered with a continuous layer not less than *one inch* thick of cement mortar or cement concrete, or with tiles made of clay, concrete or asbestos cement, or with not less than *one-half-of-an-inch* thickness of bitumen macadam composed of fine gravel or stone chippings with no greater percentage of bitumen than *seven per cent.*;

and any other suitable material or combination of materials affording an equal degree of fire-resistance.

SHORT-LIVED MATERIALS. By-law 79 gives a list of materials, unsuitable in permanent construction, but appropriate in the case of such temporary buildings as may be approved by a local authority for a period under Section 53 of the Public Health Act, 1936. The materials in the list are canvas or cloth, felt, wood boarding, various forms of fibre and plaster board, also plaster on wood or metal lath, and "sheet iron or steel (whether galvanized or not) which is not painted or protected by a bituminous or other not less suitable coating."

OPEN SPACE AT FRONT AND REAR OF DOMESTIC BUILDINGS. By-laws 80 to 85 deal with the provision of open space at the front and rear of domestic buildings intended to be used wholly or partly for human habitation. The open space at front is normally to be not less than 24 ft. wide, measured at right angles to the front of the building, but where the street is of less width than 24 ft. a distance not less than the width of the street plus one-half the difference between that width and 24 ft. is permissible. The requirements as to the open space at rear are as follows:—

81. There shall be provided in the rear of a domestic

building intended to be used wholly or predominantly for human habitation an open space exclusively belonging thereto and of an extent not less than *one hundred and fifty square feet*.

82.—(1) The open space required by the last preceding byelaw shall extend throughout the entire width of the building, and the distance across the open space from the line of the rearmost wall of the building and from any projection from the building to the boundary of any lands or premises immediately in the rear of the building shall be not less in any part than—

(*a*) *fifteen feet*, if the height of the building is not more than *twenty-five feet*;

(*b*) *twenty feet*, if the height of the building is more than *twenty-five feet* but is not more than *thirty-five feet*;

(*c*) *twenty-five feet*, if the height of the building is more than *thirty-five feet* but is not more than *fifty feet*.

(2) Where by reason of the exceptional shape of the site of the building the distance across the open space required by paragraph (1) of this byelaw cannot be obtained throughout the entire width of the building, it shall be sufficient if the mean distance across the open space is not less than the required minimum distance.

(3) If the height of the building exceeds *fifty feet*, the distance across the open space shall be such a distance as is equal to not less than *half* the height of the building, and, if in consequence of the exceptional shape of the site or of the design of the building it is not reasonably practicable to provide such open space at the rear of the building, it shall be sufficient if so much of the open space as it is not practicable to provide at the rear of the building is provided at a side of the building other than the front.

By-law 83 deals with the special cases of a building on a site abutting on two streets, and of a re-erected building.

By-law 84 provides that in a building where the accommodation for human habitation is wholly above the ground floor the open space required by By-laws 81 to 83 may be provided at the level of the lower floor at which there is accommodation for habitation, and that, for the purpose of such by-laws, the height of the building shall be measured from that level.

VENTILATION. By-laws 88 to 93 deal with questions of ventilation. Every habitable room is to have a window opening directly into the external air; the window is to have an area not less than one-tenth the floor area, and a portion of the window not less than one-twentieth of the floor area is to be arranged to open. There are also certain special rules in regard to the windows of habitable rooms opening into courts. The lowest floor of a domestic building, if it is an open-joist floor, is to be properly ventilated. Every habitable room without a fireplace, in addition to any ventilation afforded by a window or a door, is to be provided "with a fanlight opening to a ventilated lobby or corridor, or other sufficient aperture or air-shaft having an unobstructed sectional area of not less than 30 sq. in." A larder is to be ventilated by an opening with a fly-proof cover. In a building intended for separate occupation by more than two families the common staircase is to be adequately ventilated.

HEIGHT OF ROOMS. The rules on this subject are contained in By-law 94—

94. Every room intended for human habitation in a building shall comply with the following requirements:

(1) if the room is not a room wholly or partly in the roof of the building, it shall in every part except beneath an uncovered beam or joist be *eight feet* at the least in height;

(2) if the room is a room wholly or partly in the roof of the building, it shall be *eight feet* at the least in height over not less than *one-half* of the area of the room, measured at a height of *five feet* above the floor level of the room.

DRAINS. By-laws 95 to 101, which are the first group of by-laws in Part III, deal with drainage and sanitary fittings. The lowest storey of a building, except a cellar or similar space for storage, must be at such a level that it can be drained. The roof of every building, except where covered with thatch, is to have gutters and down pipes. By-law 97 contains very important detailed requirements in regard to drains—

97. Every drain (other than a subsoil drain or a drain for the conveyance solely of trade effluent) constructed in connection with a building shall comply with such of the following requirements as are applicable—

(1) it shall be constructed of good sound pipes of suitable material, and this requirement shall be deemed to be satisfied if new glazed ware pipes conforming to either British Standard Specification No. 65—1937 or No. 540—1937, or new cast iron pipes conforming to British Standard Specification No. 437—1933, or new concrete pipes conforming to British Standard Specification No. 556—1934, are used;

(2) it shall be properly supported and protected against injury, laid at a proper inclination, and provided with suitable watertight joints;

(3) it shall be capable of withstanding a reasonable hydraulic test, smoke or air test under pressure, or other suitable test;

(4) it shall be of adequate size, and if intended for the conveyance of foul water shall have an internal diameter of not less than *four inches*;

(5) where it passes through a building it shall to that extent be constructed of cast iron or other not less suitable metal;

(6) where it is laid on or in the ground—

(*a*) if it is constructed of material other than cast iron or other metal of not less strength, it

shall, so far as it lies within a distance of *fifty feet* from the building, be laid on a bed of concrete unless the nature of the soil renders this unnecessary;

(*b*) if it is constructed of corrosible material, it shall be suitably protected inside and outside against corrosion;

(7) no part of the drain shall be laid under any building where any other mode of construction is practicable;

(8) where a part of the drain is laid under a building, that part shall—

(*a*) be laid in a straight line for the whole extent beneath the building or, if this is impracticable, in a series of straight lines;

(*b*) if laid in the ground and constructed of material other than cast iron or other metal of not less strength, be completely surrounded with concrete not less than *six inches* thick;

(*c*) be provided with adequate means of access for its whole length and, if not laid in one straight line, be provided with an inspection chamber at each change of direction;

(9) every inlet to the drain, other than an inlet provided for the ventilation of the drain, shall be properly trapped.

Other by-laws deal with drains for trade effluents, the protection of drains passing under walls, the proper lay-out of drains, and the permitted manner of making connections to drains within buildings.

By-law 102 requires that a drain for foul water shall be provided with at least one ventilating pipe, as distant as practicable from the point where the drain joins the sewer; a soil pipe from a watercloset or a waste pipe from a slop sink, carried up to the requisite height, may serve as a ventilating pipe.

SOIL AND WASTE PIPES. The requirements as to soil and waste pipes from waterclosets and slop sinks are given in By-law 103—

103. The soil pipe from a watercloset, and the waste pipe from a slop sink, other than parts of such pipes carried up as ventilating pipes, shall be—

(1) formed of suitable material, and this requirement shall be deemed to be satisfied if new cast iron pipes conforming to British Standard Specification No. 416–1935 for heavy grade pipes, or new lead pipes conforming to either British Standard Specification No. 602–1939 or No. 603–1935, are used;

(2) of an internal diameter not less than that of any pipe connecting it with the watercloset or slop sink, and in any case not less than *three inches*.

By-laws 104 and 105 give rules for ventilating pipes, whether specially provided pipes or soil or waste pipes carried up as ventilating pipes. Such pipes are "to be formed of suitable material to secure durability" and are to be carried up "to such a height and in such a manner as effectually to prevent the escape of foul air from the drains into any building."

The rules for waste pipes from baths, etc., are given in By-law 106.

106. A waste pipe from a bath, sink (not being a slop sink), bidet or lavatory basin, and a pipe for carrying off dirty water, shall—

(1) discharge so as not to cause dampness in a wall or foundation of a building;

(2) if it discharges to a drain otherwise than by a soil pipe from a watercloset or a waste pipe from a slop sink, be disconnected from the drain by a trapped gully with a suitable grating above the level of the water in the trap;

(3) if it is more than *six feet* in length, be provided with a suitable trap;

(4) if it discharges into a soil pipe from a watercloset or a waste pipe from a slop sink, be provided whatever its length with a suitable trap adequately secured against destruction of the water seal.

ALTERATIONS IN MODEL CLAUSES. Until recently the Model Code contained a clause requiring an intercepting trap to be provided near the junction of a drain with the sewer, with two ventilating pipes to the drain. It will be seen that By-law 102 requires only one ventilating pipe, and that there is no requirement for an intercepting trap. In some districts, however, it may be found that the local by-laws still require an intercepting trap and two ventilating pipes. It should be noted that By-law 106 allows alternative arrangements in the case of waste pipes from baths, sinks, etc., namely, (*a*) the waste pipe may discharge over or into a trapped gulley above the level of the water seal, or, (*b*) it may discharge into a soil pipe, this latter alternative permitting the adoption of the one pipe system of drainage. It may, however, possibly be found in some districts that this is not allowed by the local by-laws.

PRIVATE SEWERS. These are dealt with in By-laws 108 and 109. Private sewers are to be constructed in a similar manner to drains and of similar materials.

WATERCLOSETS. By-law 110 deals with the fittings of waterclosets, and with matters of lighting and ventilation. The closet pan is to be of non-absorbent material, and of suitable shape; an efficient flushing apparatus is to be provided; where the watercloset discharges into a soil pipe which receives the discharge from another watercloset or from another fitting, the trap is to be ventilated against syphonage by a pipe not less than 2 in. diameter.

The rules for the lighting and ventilation of waterclosets are as follows—

(7) where the watercloset is in connection with a domestic building and is entered directly from the

external air, it shall be provided with a sufficient opening for lighting and ventilation as near the top as practicable and communicating directly with the external air;

(8) where the watercloset is in a domestic building and is not entered directly from the external air, it shall either—

(*a*) have an external wall for at least one of its sides and a window of an area of not less than *two square feet*, exclusive of the frame, opening directly into the external air; or

(*b*) be sufficiently ventilated by mechanical means and sufficiently lighted;

(9) for the purpose of this byelaw the expression "watercloset" shall include any room which is partitioned or divided into two or more cubicles, each containing a pan, if the partitions or divisions are so constructed as to allow the free circulation of air throughout the room.

URINALS. By By-law 111 a urinal connected with a building which has a supply of water laid on is to have a basin, stall or trough of non-absorbent material, and is to be provided with a suitable flushing apparatus. If the urinal can be entered from the building and it discharges into a soil pipe which receives the discharge from another fitting, the trap of the urinal is to be ventilated against syphonage.

EARTHCLOSETS. These are dealt with in By-law 112. An earthcloset is to be so situated that its only direct entrance is from the external air, and it is to be not less than 40 ft. from any well, spring or stream. It is to be provided with a sufficient opening for light and ventilation as near the top as practicable and communicating directly with the external air. Detailed requirements are given in regard to the construction of the floor, the size of the receptacle for faecal matter, and the finish of the internal surface of the walls under the seat.

ASHPITS. By By-law 113 an ashpit is to be situated not less than 10 ft. from any dwelling-house or public building, or any building in which any person is employed in any manufacture, trade or business, and not less than 30 ft. from any well, spring or stream. Detailed requirements are given as to the construction of the floor and walls.

CESSPOOLS. The rules for cesspools are given in By-law 115; those dealing with the position of a cesspool are as follows—

A cesspool constructed in connection with a building (other than a tank intended for the reception or disposal of trade effluent) shall comply with the following requirements:—

(1) it shall be—

(*a*) not less than *fifty feet* from any dwelling-house, or public building, or any building in which any person is employed in any manufacture, trade or business;

(*b*) not less than *sixty feet* from any well, spring or stream of water, used or likely to be used by man for drinking or domestic purposes, or for the manufacture or preparation of articles of food or drink for human consumption, or for the cleansing of vessels with a view to the preparation or sale of such articles, and otherwise in such a position as not to render any such water liable to pollution;

A cesspool is to be so situated that its contents may be removed without carrying them through a building, and it is to be constructed so as to be impervious to liquid, either from the outside or from the inside.

WELLS. By-law 117 contains the rules for wells; those dealing with the position of a well are as follows—

117. A well constructed in connection with a building and intended to supply water for human consumption shall comply with the following requirements:—

(1) it shall be—

(*a*) not less than *thirty feet* from any ashpit;

(*b*) not less than *forty feet* from any earthcloset or privy;

(*c*) not less than *sixty feet* from any cesspool;

Detailed rules are given in regard to the formation of both dug and bored wells.

RAINWATER TANKS AND CISTERNS. By-law 118 contains rules for the construction of tanks or cisterns for the storage of rainwater.

HEARTHS FOR CLOSE STOVES. By-law 119 deals with the protection against fire of the floor beneath a close stove, boiler, etc (not heated by gas or electricity) where the fitting is not placed on an ordinary hearth.

GAS FIRES AND GEYSERS. These are dealt with in By-laws 120 and 121. Every gas fire in a habitable room is to have an adequate flue pipe, discharging either into a chimney or directly into the external air, in which latter case it is to be provided with a proper terminal or outside windguard. The flue pipe from a geyser must be of a diameter not less than that of the spigot at the top of the geyser, it must have a proper baffler and must discharge either into a chimney or into the external air with a proper terminal or windguard, or it may discharge into a freely-ventilated roof space. The fitting of a geyser in a room without a window is prohibited. The window must be capable of being opened.

GIVING OF NOTICE AND SUBMISSION OF PLANS. These matters are regulated by By-laws 122 to 124 which provide that any person who proposes to erect a building or to carry out drainage work is to notify the local authority and to submit plans in duplicate. By-law 122 also provides that any person who proposes to make a material change in the use of a building is to notify the local authority.

Chapter VI—LONDON BUILDING LAW

Administration. Whereas in a provincial town there is only one authority, the local city, borough or district council, controlling the erection of buildings, in London there are three authorities, each with clearly marked duties in respect of the administration of the London Building Law. The principal authority is, of course, the London County Council. Then there are the various district surveyors, who are salaried officials of the County Council, but have important powers vested in them under the London Building Acts by reason of their position. The district surveyors have control over all building operations of an ordinary character, other than drainage work. The authorities for dealing with drainage work are the Metropolitan Borough Councils, to whom drainage plans of all proposed new buildings must be submitted. In the City area the City Corporation controls drainage in a similar manner to a borough council, except that it operates its own by-laws and not those in force throughout the rest of London. The London County Council controls under the Building Acts the formation of streets, the frontage line of buildings, the means of escape from buildings in case of fire, the erection of the more important classes of temporary buildings and structures, and the remedying of dangerous structures. The Council regularly deals with numerous applications for consent to proposed works which do not comply with the general requirements of the Building Acts, and also with applications for waivers of the by-laws. The superintending architect of the County Council has certain important powers by virtue of his position, and there is also a Tribunal of Appeal to whom appeals may be made in certain cases. The County Council is also the town planning authority for the whole of the County, except the City, in which area the City Corporation is the authority, and it administers that portion of the Restriction of Ribbon Development Act, 1935, which applies in London.

The word "London," as here used, means the County of London, and it should be noted that there are several populous districts, such as Ealing, East and West Ham, Croydon, etc., which are outside the County. In such districts the ordinary provincial building law applies. The County area should not be confused with "the London Region" for civil defence purposes during the war, which was several times larger than the County.

Acts of Parliament. The principal Acts of Parliament controlling the erection of buildings in London are the London Building Act, 1930, the London Building Act (Amendment) Act, 1935, and the London Building Acts (Amendment) Act, 1939. These Acts, however, do not contain any requirements as to sewerage or drainage. Such requirements were at one time contained in the Metropolis Management Act, 1855, and its Amending Acts, but are now to be found in the Public Health (London) Act, 1936. In the case of the City of London, the provisions of this Act, however, do not apply, and the requirements dealing with sewerage and drainage are contained in the City of London Sewers Acts, 1848 and 1851. The by-laws as to building work in London are made under the London Building Acts. Those as to drainage and sanitation are made under the Metropolis Management Acts and the now repealed Public Health (London) Act, 1891, as regards the Metropolitan Boroughs, and under private City Acts as regards the City of London.

When the London Building Act, 1930, became law it contained practically all the requirements in regard to building, other than those affecting sewerage, drainage and sanitation. Although this Act is still unrepealed in the case of several Parts, and is still the main Building Act, it has been so affected by repeals and new legislation that the greater portion of it is no longer applicable. The London Building Act (Amendment) Act, 1935, gave power to the County Council to make by-laws in regard to a number of matters, many of which at the passing of that Act were controlled by the provisions of Part VI of the London Building Act, 1930. This Act of 1935 contains a schedule in which is given a list of sections and portions of sections of the 1930 Act, and Section 12 of the Act provides that where any by-law made in pursuance of that Act replaces any enactment in the 1930 Act given in such

schedule, the requirement of the 1930 Act is thereby repealed. By-laws dealing with building work were made by the Council in 1937, and, as a result, under the provisions of the above-mentioned Section 12 of the 1935 Act, most of the requirements of Part VI of the 1930 Act, and the whole of the Second and Third Schedules, have been repealed and replaced by by-laws. The Council also in the same year issued by-laws regulating the use of timber in the construction of buildings. These were new requirements and did not replace any of the provisions of the 1930 Act, and they are issued as a separate document. Both these sets of by-laws came into operation on 1st January, 1938.

The law in regard to building work in London was very much changed by the London Acts (Amendment) Act, 1939. This Act, among other things, repealed those portions of Part VI of the Act of 1930, which had not been repealed by the making of by-laws, and it repealed also those portions of the 1930 Act dealing with temporary buildings, dangerous structures, means of escape in case of fire, rights of building and adjoining owners, together with Parts XIV to XVII, dealing in the main with administrative matters. It also repealed the First, Fourth and Fifth Schedules of the Act, dealing with, respectively, fire resisting materials, and the payment of fees in regard to dangerous structures and general building work. The above-mentioned subjects are now controlled by the provisions of the 1939 Act.

The only provisions of the 1930 Act now in force that are of general interest are certain of the definitions in Part I; Part II, dealing with the formation and widening of streets; Part III, regarding lines of building frontage; and Part V, in regard to open space about buildings and the height of buildings. Parts XI and XII, dealing with respectively dangerous and noxious businesses, and dwelling-houses on low-lying-land, are also unrepealed, but have from their subject-matter only limited application. The detailed requirements as to the construction of buildings are for the most part in the by-laws, but very important requirements are contained in Part III of the 1939 Act, headed "Construction of Buildings," and Part IV, headed "Special and Temporary Building and Structures." The subjects of means of escape in case of fire, rights of building and adjoining owners, dangerous and neglected structures, and of sky-signs are dealt with in Parts V, VI, VII and VIII of the 1939 Act. Certain further constructional requirements, and also a list of buildings that are wholly or partially exempt from the London Building Acts and by-laws, are contained in Part XII of such Act.

In addition to the above-mentioned Acts and by-laws, there are several Acts of general application, in force equally in London and the provinces, the principal of which are the Town Planning Acts, the Housing Act, 1936, and the Factories Act, 1937. These Acts, together with the Restriction of Ribbon Development Act, 1935, of which a portion applies in London, are dealt with in Chapter VIII.

Formation of Streets. Any person who proposes to form a new street in the County of London must submit plans to the County Council. Section 9 of the London Building Act, 1930, provides that the Council may disapprove plans submitted for a new street in any of the following cases (but not any other case)—

(1) Where the street is to be used for vehicular traffic and is less than 40 *feet* in width,

(2) Where the street is to be used for foot traffic, and is less than 20 *feet* in width.

(3) Where the street exceeds 60 *feet* in length, and is not open at both ends.

(4) Where the street does not form a direct communication between two other streets.

(5) Where the street is proposed to be used for foot traffic only, and the Council consider that its use should not be limited in this way.

(6) Where, in the case of a vehicular-traffic street, the gradient is steeper than one in twenty.

(7) Where the street contravenes a byelaw of the Council.

Nos. 4 and 5 of the foregoing requirements do not apply in the City of London.

It is now necessary to obtain, also, the consent of the County Council to the formation of a new street under the Town Planning Acts, and it does not follow that a street lay-out in accordance with the London Building Acts will necessarily be approved under the Town Planning Acts. Particulars of the Town Planning Acts are given in Chapter VIII.

By-laws controlling the construction of new streets have been made by the County Council. Such by-laws require, among other things, that the carriage-way must fall, or curve, at the rate of ⅜ in. in every foot of width, that the kerb must not be less than 4 in., or more than 8 in., above the channel, and that the slope of the footpath towards the curb must be ½ in. to every foot of width if the footpath be unpaved, and not less than ¼ in. to every foot of width if the footpath be paved.

PRIVATE STREETS. The paving of private streets is controlled in London by the local borough councils, under the Metropolis Management Act, 1855, and its amending Acts of 1862 and 1890. Under Section 77 of the Metropolis Management Amendment Act, 1862, the borough council may, if they so desire, charge the owners of land in a less proportion than the owners of house property, and may at their discretion accept payment of the amount charged by instalments, spread over a period not exceeding twenty years. Under Section 80 of this Act, the borough council are not entitled to pave a private street if not less than two-thirds of the owners, or rated occupiers, of the houses give them written notice of objection to their proposals.

Sewerage. The law in regard to this subject was at one time contained in the Metropolis Management Act, 1855, and its amending Acts. The sections of such Acts which had reference to this subject, and that of drainage, were repealed by the Public Health (London) Act, 1936, and were replaced by the provisions of Part II of that Act, comprising Sections 14 to 81.

It should be noted that, by Section 76, the rights of the City Corporation to operate their own Acts and By-laws in regard to sewerage and drainage are not affected.

Sewers in the County of London are either main sewers vested in the County Council, or subsidiary sewers vested in the borough councils, there are also certain old sewers which are maintained by private owners. A considerable portion of Part II of the Act of 1936 deals with the respective duties of the County Council and the borough councils in regard to sewerage. The principal sections which concern private owners are Sections 19, 23, and 37 to 45. By Section 19, where a private owner had before 1856, a liability to maintain a sewer, and the borough council considers that the sewer should be altered or improved, the borough council may do the work, and apportion the cost between themselves and the private owner. By Section 23 a borough council has the right, when they construct a new sewer in a street, to apportion the cost among the owners of the land abutting on the street.

Drainage. This subject is dealt with in Sections 37 to 45, and in Drainage By-laws, which are referred to at the end of Chapter VII. Section 37 provides that it is not lawful to erect any building or to re-build any building which has been pulled down to or at a level below "the floor commonly called the ground floor" unless drains to the approval of the borough council are provided. If there is a sewer within 100 feet the drainage must be run to the sewer; if not, the drainage may be to a covered cesspool "or other place" as the council may direct. Section 38 gives the council power, in the case of a building which is not satisfactorily drained, to require a proper drainage system to be provided; where a group of houses is dealt with under this section and they can be more economically drained in combination than separately, the council may require them to be drained by a combined operation. Section 39 deals with the supervision of new drainage work by the borough council, and Section 40 gives the council power to inspect existing drains.

DEFINITIONS OF "DRAIN" AND "SEWER." These important definitions are given in Section 81 of the Act and are as follows—

"drain" means a drain used for the drainage of one building only or premises within the same curtilage, being a drain made merely for the purpose of communicating with a cesspool or other like receptacle for drainage or with a sewer into which the drainage of two or more buildings or premises occupied by different persons is conveyed, and includes -

(*a*) a drain for draining any group or block of houses by a combined operation under an order of a borough council or their predecessors; and

(*b*) a drain for draining a group or block of houses by a combined operation, being a drain laid or constructed before the year 1856 in pursuance of an order or direction of, or with the sanction or approval of, the Metropolitan Commissioners of Sewers;

"sewer" means a sewer or drain of any description, except a drain as hereinbefore defined.

PROTECTION OF SEWERS. Sections 56 to 64 prohibit the discharge of injurious solids or liquids into sewers. Section 66 prohibits the erection of a building over a sewer without the consent of the authority in whom the sewer is vested.

RIGHTS OF APPEAL. Section 71 provides that any person aggrieved by any act, order or resolution of a borough council in regard to sewerage or drainage work, or in regard to the payment of expenses of sewer construction, has the right, within seven days, to appeal to the County Council.

Frontage of Buildings. Section 22 of the London Building Act, 1930, deals with the frontage of buildings, and is as follows—

(1) No building or structure shall without the consent in writing of the Council be erected or brought forward (notwithstanding that there are gardens or vacant spaces between the line of buildings and the highway)

(*a*) beyond the general line of buildings in any street or part of a street place or row of houses in which the same is situate if the distance of such line of buildings from the highway does not exceed 50 *feet*; or

(*b*) within 50 *feet* of the highway if the distance of the general line of buildings therefrom exceeds 50 *feet*.

The general line of buildings shall if required be defined by the superintending architect by a certificate to be issued within one month from the date of the application therefor.

(2) Nothing in this section shall affect the erection or bringing forward of any building or structure upon or over land which at any time during the period of seven years immediately preceding the first day of January eighteen hundred and ninety-five was lawfully occupied by a building or structure.

Section 22 is contained in Part III of the Act, which part does not apply in the city of London, so that the section does not affect the erection of buildings in the city.

Section 131 of the London Building Acts (Amendment) Act, 1939, which deals with projections from buildings, must be read in conjunction with Section 22. This section contains particulars of projections, including cornices, porches, balconies, shop fronts, bay windows, and oriel windows, which may project to a limited extent beyond the general line of buildings. The extent of projection is regulated principally by the width of the street, the maximum projection being 5 ft. for cornices, 3 ft. for porches, balconies, bay and oriel windows, and 10 in. for shop fronts. No projection, except cornices and oriel windows, may extend over the public way, and there is a limit of 12 in. over the public way for oriel windows.

The London Building Act, 1930, also contains certain requirements regarding the position of buildings in narrow streets. Section 13 of the Act prohibits the erection of any new building, or structure, in such a manner that it extends within the prescribed distance from the centre of the roadway of the street. Section 5 of the Act defines "prescribed distance" as being 20 ft. from the centre of the roadway in the case of a vehicular-traffic street, and 10 ft. from the centre in the case of a foot-traffic street. The re-erection of buildings which existed on 1st January, 1895, within the prescribed distance, is permitted by Section 13, provided that, before the existing buildings are pulled down, a plan of such buildings is made and is certified by the district surveyor.

Open Space at Rear of Buildings. Part V of the London Building Act, 1930, comprising Sections 42 to 56, deals with open spaces about buildings and the height of buildings. Section 42 states that in this part of the Act, the expression "domestic building" shall not include any buildings used, or constructed, or adapted to be used wholly or principally as offices or counting-houses. Section 43 provides that, where a new domestic building has a habitable basement, an open space of not less than 100 sq. ft. must be provided at the level of the adjoining pavement, for the purpose of giving light and air to such basement. Section 44 deals with the question of space at rear of domestic buildings. The requirements of this section are very complex, and it is possible to give only a brief summary of the principal provisions. Persons who are concerned with any new building coming within the scope of the section are strongly advised to obtain a copy of the Act, and read carefully the detailed provisions of the section. The minimum open space at rear, required under the section, is 150 sq. ft.; but this minimum is, in effect, increased in many cases by a further requirement that the open space shall extend throughout the entire width of the building, and be at least 10 ft. in depth. In streets laid out since 1894, the open space is, generally speaking, to be provided at the level of the street pavement. In the case of streets formed before 1894, the open space is to be provided at a level of 16 ft. above pavement level, except in the case of dwellings for the working classes, in which case the open space is to be provided at pavement level.

The provisions of Section 44, in addition to dealing with open space at rear, also limit the height of the rear elevation. The section provides that an imaginary diagonal line is to be drawn from the rear boundary of the site at an angle of 63½° with the horizontal, and that no portion of the rear elevation of the building, except chimneys, dormers, etc., may extend above the diagonal line. The level at which the diagonal line is commenced to be drawn will depend upon the age of the street. In the case of buildings abutting on streets formed after 1894, the line is to be drawn at the level of the street pavement as shown in Fig. 1 (*a*). Where buildings abut on streets formed before 1894, the diagonal line is to be commenced to be drawn at a level of 16 ft. above the street pavement, as shown in Fig. (*b*). It is provided, however, by Section 46 that an existing domestic building may be re-erected to the same height and extent, if plans of it are certified by the district surveyor.

Section 48 of the Act deals with courts within a building, and should be consulted by any person who is proposing to erect a building with habitable rooms lighted from an internal area.

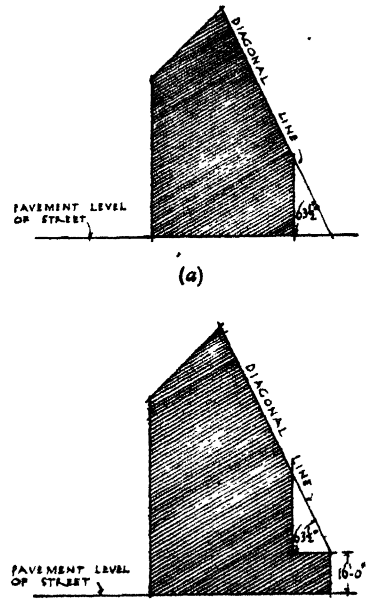
Height of Buildings. Sections 51 to 55 deal with the height of buildings. Section 51 commences as follows—

A building (not being a church or chapel) shall not be erected of or be subsequently increased to a greater height than 80 *feet* (exclusive of two storeys in the roof and of ornamental towers turrets or other architectural features or decorations) without the consent of the Council.

Generally speaking, the limit of height there given has been adhered to by the County Council, although in a few cases, in sites facing wide streets, approval has been given to a somewhat greater height than 80 ft.

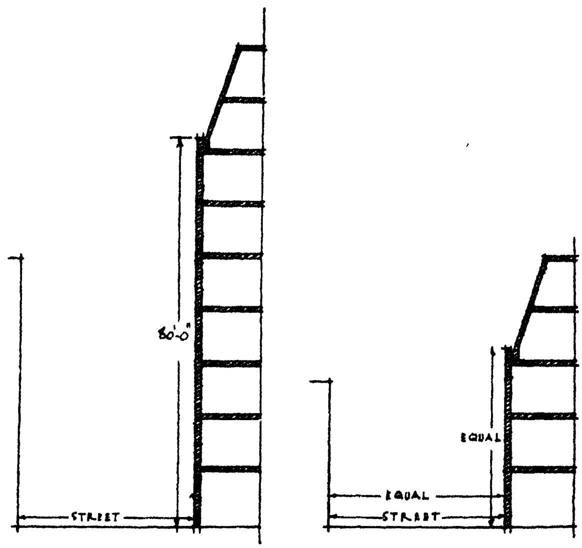
Section 53 puts a lower limit on the height of buildings abutting on streets laid out after 1862, and of a less width than 50 ft. No building abutting on any such street may be erected to a greater height than the distance of the front external wall of the building from the opposite side of the street. In dealing with buildings where the proposed height appears to approximate to, or exceed, the limit imposed by the Act, it will be necessary to consult the definition of height. This is given in Section 4 of the London Building Acts (Amendment) Act, 1939, as follows—

"Height" in relation to any building means the measurement taken at the centre of the face of the building from the level of the footway immediately in front of such face or where there is no such footway from the level of the ground before excavation to the level of the top of the parapet or where there is no parapet to the level of the top of the external wall or in the case of a gabled building to the level of the base of the gable.



(b)

FIG. 1



(a) (b)

FIG. 2

The ordinary maximum permissible height of a building in any street formed before 1862 is shown in Fig. 2 (*a*) and that of a building in a street less than 50 ft. wide, and formed after 1862, is shown in Fig. 2 (*b*).

It should be noted, however, that under Section 20 of the London Building Acts (Amendment) Act, 1939, there is a further limitation of the total vertical extent of a building, irrespective of the age of the street.

It should be noted also that in the case both of open space and of height, the consent of the Council, except in the City, is now necessary under the Town Planning Acts, and it does not follow that compliance with the London

Building Acts will ensure approval under the Town Planning Acts.

Construction of Buildings. The requirements in regard to this subject are of two kinds, namely (*a*) those which apply because of the size and use of a building, and have reference only to certain parts of a building, and (*b*) those which apply to all buildings, and regulate the construction of all parts of a building. Requirements (*a*) will be found in two of the General Building By-laws, Nos. 140 and 144, and in certain sections of the London Building Acts (Amendment) Act, 1939, the principal of which are contained in Part III. Requirements (*b*) are for the most part contained in the by-laws.

Buildings Regulated by Size and Use. The smallest kind of building affected by requirements of the nature referred to in (*a*) is a shop or workshop with dwelling accommodation. By-law 144 provides that in every building exceeding 10 squares in area, used in part for trade or manufacture and in part as a dwelling-house, the first-mentioned part is to be separated from the dwelling-house part by walls and floors of fire-resisting materials, and that all passages and staircases to the dwelling-house part are to be of fire-resisting materials. Door opening may be made in walls, provided that the doors and door frames are of fire-resisting materials. A square is 100 sq. ft., so that the by-law applies to all buildings of the kind mentioned if they exceed 1,000 sq. ft. in area.

By-law 140 applies to such buildings as flats, tenement factories, office buildings with rooms let to different tenants, and other similar multi-occupational buildings, if of a certain size. The by-law provides that in every building which exceeds 25 squares in area or 125,000 cubic feet in extent, and is to be tenanted by different persons, all the floors, and also all lobbies, corridors, passages, landings and stairs used in common by the tenants, are to be constructed of fire-resisting materials. The section further provides that the lobbies, corridors, passages, etc., used in common are to have enclosures of terra-cotta, brick, concrete or other incombustible material not less than 3 in. thick.

Sub-division of Certain Buildings. Section 20 of the London Building Acts (Amendment) Act, 1939, provides that, unless the Council otherwise consent, no building of the warehouse class and no building or part of a building used for trade or manufacture may exceed 250,000 cub. ft. unless it is sub-divided into units not exceeding 250,000 cub. ft. The term "building of the warehouse class" is defined in Section 5 of the London Building Act, 1930, as follows—

> Building of the warehouse class means a warehouse manufactory brewery or distillery or any other building exceeding in cubical extent 150,000 cubic feet which is neither a public building nor a domestic building.

Section 22 of the Act of 1939 provides that a division wall shall in all respects conform to the rules relating to party walls. Section 21 of this Act contains the rules for openings in party and division walls, the size of such openings being limited, and the provision of double iron doors or shutters being necessary. It is a common practice for persons erecting large trade buildings to apply to the Council for consent to the formation of units larger than 250,000 cub. ft. Consent to an increase of cube is usually granted in the case of buildings of steel-frame or reinforced concrete construction, subject to various conditions, among which are usually conditions that openings to staircases and lifts shall be provided with steel shutters and fire-resisting doors to prevent the spread of fire from floor to floor, and that the building shall be provided with a sprinkler installation, designed to nip in the bud any outbreak of fire.

Public Buildings. Buildings of this class are subject to the special requirements contained in Sections 25 to 27 of the Act of 1939. The term "public building" is defined in Section 4 of the Act as meaning—

> (*a*) a building used wholly or partly as a church chapel or other place of public worship (not being a dwelling-house so used) or as a public assistance institution or public library or as a place for public entertainments public balls public dances public lectures or public exhibitions or otherwise as a place of public assembly; or
>
> (*b*) a building of a cubical extent exceeding two hundred and fifty thousand cubic feet which is used wholly or partly as an hotel or hospital or as a school college or other place of instruction;

Section 25 provides that in every public building the floors of the lobbies, corridors, passages and landings and the flights of stairs shall be constructed of and carried by supports of such a degree of fire-resistance as the Council may determine. Section 26 deals with the general construction of this class of buildings, and provides that "every public building including the walls, roofs, floors, galleries, and staircases, and every structure and work constructed or done in connection with or for the purposes of the same shall be constructed in

such manner as may be approved by the district surveyor or determined by the Tribunal of Appeal." The remaining parts of the section deal with the prescribing by the Council of standards of stability and fire-protection in the construction of public buildings, the rules for the relaxation of these standards if desirable in any particular case, and the right of a district surveyor to require a higher standard in any particular case, if he thinks fit. Section 27 provides that, in the conversion of an ordinary building into a public building, the rules in regard to the construction of public buildings shall apply.

Places of Public Entertainment. Theatres, music halls, cinemas and similar buildings are licensed by the Council. As public buildings they are subject to the jurisdiction of the district surveyor under Section 26 of the 1939 Act, and they must comply also with Regulations issued by the Council under the Metropolis Management and Building Acts Amendment Act, 1878. These regulations deal not only with the building but with the site. In normal circumstances the site is required to have long frontages to two streets, and, to be acceptable under the regulations, the streets are to be of such a width that persons can disperse rapidly in the case of fire or panic. The regulations contain detailed requirements in regard to fire-resisting construction, fire escape, sanitary accommodation, lighting, heating and ventilation. Copies of the regulations may be obtained, price 1/-. from any bookseller or from P. S. King, Ltd., 14 Gt. Smith Street, Victoria Street, Westminster, S.W.1, agents for the Council's publications.

Special and Temporary Buildings and Structures. The rules for these are contained in Part IV, of the Act of 1939. The buildings and structures to which this Part applies are defined in Section 29 as being—

(*a*) any building or structure not constructed or not intended to be constructed generally or substantially in conformity with the provisions of Part III (Construction of buildings) of this Act and of any byelaws made in pursuance of the London Building Acts;

(*b*) any structure the construction of which is not regulated by the provisions of the said Part III and byelaws.

Common examples of such buildings or structures are bunkers, gantries, crane structures, external lift structures, etc., and various forms of temporary buildings and sheds. Special application for approval is necessary under the provisions of Section 30. In the case of all the larger buildings and structures, application must be made to the County Council, who have power under Section 144 of the Act to attach conditions to any approval, and often give approval for a term of years only, such term being extended in most instances from time to time, subject to a certificate of structural stability and satisfactory condition being issued by the district surveyor.

In the case of certain less important buildings and structures the section provides that the borough council shall be the administrative authority. These buildings and structures may be briefly summarized as follows—

(*a*) Any building or structure which does not exceed two hundred square feet in area or seven feet six inches in height, measured to the underside of the eaves or roof plate, and which does not contravene any of the provisions of Parts II, III and V of the Act of 1930, or any scheme or order under the Town Planning Acts.

(*b*) Any temporary stand of which the topmost tier is not more than seven feet above the footway.

(*c*) Any other structure (not being a building) wholly or mainly of wooden construction.

It is specially provided, however, that a borough council is not entitled to approve any building or structure which is used for the storage or manipulation of inflammable material, or for human habitation, or which is united to a building of regular construction.

OPEN SHEDS. The last section in Part IV (No. 32) provides that, notwithstanding anything in the London Building Acts and by-laws, open sheds not exceeding 16 ft. in height and 6 squares in area may be constructed of any materials approved by the district surveyor.

Other Provisions of Part III of 1939 Act. In addition to the provisions of Part III already summarized, attention is drawn to requirements affecting the following: party walls (Sections 16 and 17); bay windows, etc. (18); roof drainage (19); ventilation of staircases (24). There are also the important requirements of Sections 21, where it is provided that buildings are not to be united without the consent of the Council unless they are wholly in one occupation, and when so united and considered as one building they would be in conformity with the London Building Acts and by-laws. Another provision which affects very materially the design of large buildings is that contained in the first part of Section 20, which is as follows—

(1) Unless the Council otherwise consent—
(a) no building shall be erected with a storey or part of a storey at a greater height than—
(i) one hundred feet; or
(ii) eighty feet if the area of the building exceeds ten thousand square feet;

It is provided, however, later in the section, that the Council shall not withhold consent if they are satisfied that proper arrangements will be made and maintained for lessening danger from fire.

PROVISIONS OF PART VI OF 1939 ACT. These important provisions, which determine the rights of building and adjoining owners, have already been dealt with in Chapter III.

PROVISIONS OF PART XII OF 1939 ACT. Attention is invited to the various provisions of this Part which is headed "Miscellaneous," some of which, in particular Section 30, dealing with bridges over highways, and Section 131, already mentioned, containing a list of parts of a building which may project to a limited extent in advance of the general line of buildings, are of considerable practical importance. There is also Section 136 which defines the extent of reconstruction that makes a building one "deemed to be erected after the commencement of the Act."

Payment of Fees. Fees are payable by builders in the case of all building work in the County of London. Until the passing of the 1939 Act, the fees were payable to the district surveyors, who derived their incomes and maintained their offices from this source. District surveyors are now paid by salary and all fees are payable to the Council. The fees are set out in detail in the 2nd Schedule of the 1939 Act. Fees on additions and alterations are based on the cost of the work, and those for new buildings on the cube of the building. In the case of public buildings the fees are increased by fifty per cent, and in the case of new buildings of steel frame or reinforced concrete construction, including new public buildings of this type, the fees are doubled.

Exempted Buildings. Sections 149 to 152 of the 1939 Act contain the principal provisions in regard to exempted buildings. Government buildings are wholly exempt. Buildings of the Inns of Court, and buildings of railway, canal, dock, gas and electricity companies are very largely exempt. Section 149 also contains provisions exempting certain buildings and structures from Parts III and IV of the 1939 Act, if they do not exceed a certain size and are a certain distance away from a street or from the land of an adjoining owner. Buildings thus exempted are stated to be as follows—

(k) Any building not exceeding in area thirty square feet and not exceeding in height five feet in any part measured from the level of the ground to the underside of the eaves or roof plate and distant at least five feet from any other building and from any street and not having therein any stove flue fireplace hot-air pipe hot-water pipe or other similar apparatus and not extending in any part beyond the general line of buildings in any street;
(l) All buildings (not being public buildings or buildings used for the purpose of human habitation or for trade) not exceeding in any part ten feet in height measured from the level of the ground to the underside of the eaves or roof plate and—
(i) of a superficial area not exceeding two hundred square feet and distant at least ten feet from any other building and from the land of every adjoining owner; or
(ii) of a superficial area not exceeding eight hundred square feet and distant at least fifteen feet from any other building and from the land of every adjoining owner;

Means of Escape in Case of Fire. Reference has already been made to this question as affecting theatres, music halls, cinemas and other places of public entertainment, and escape from factories is dealt with later in Chapter VIII. The general requirements on fire escape, as affecting all ordinary classes of buildings, except certain dwelling-houses, are contained in Part V of the London Building Acts (Amendment) Act, 1939. The requirements are in general terms: that buildings shall be provided with such means of escape in case of fire as can be reasonably required. The important question of course is the classes of buildings to which the requirements apply, and in this the scope of the 1939 Act is much wider than that of the repealed provisions of the 1930 Act.

NEW BUILDINGS. The scope of the requirements in the case of new buildings is determined by Section 34 of the 1939 Act as follows—

(1) Every new public building every new building which is constructed to be used or is used in whole or in part as a church chapel or other place of worship hall meeting room school classroom concert room dancing room or other place of assembly and every other new building—
(a) which if of one storey exceeds six squares in area; or
(b) which if of more than one storey has in the aggregate a total floor area exceeding ten squares (exclusive of any basement storey used solely for storage purposes); or
(c) which has a storey at a greater height than twenty feet; or
(d) in which more than ten persons are employed above the ground storey;

shall be provided in accordance with plans approved by the Council with all such means of escape therefrom in case of fire as in the circumstances of the case can be reasonably required:

There are, however, certain provisos, the first of which is that in the case of a building of class (*c*) the Council are not entitled to require escape to be provided from any storey not at a greater height than 20 ft., unless the building is also one of class (*b*) or class (*d*). A second proviso may be summarized as follows: that the section does not apply to a building which is constructed to be used only as a private dwelling house and which does not contain a storey at a greater height than 20 ft. To understand fully the scope of the section it is necessary to refer to the definition of "height" which is given in Section 33 for the purposes of Part V as follows:—

"height" in relation to a storey of a building means the level of the surface of the highest point of the floor of that storey measured at the centre of that face of the building where the measurement is greatest from the level of the footway immediately in front of that face or if there is no such footway from the level of the ground before excavation;

OLD BUILDINGS, AND BUILDINGS WITH SPECIAL RISKS. The remaining requirements of Part V deal principally with escape from old buildings and from those with special fire risks. Old buildings are dealt with in Section 35, under which the Council are empowered to require the provision of escape from the following buildings—

(1) Where an old building—

(*a*) except a dwelling-house occupied as such by not more than one family—

(i) contains any storey which is at a greater height than forty-two feet; or

(ii) is a building in which sleeping accommodation is provided for more than twenty persons or which is occupied by more than twenty persons or in which more than twenty persons are employed; or

(*b*) is a building in which more than ten persons are normally employed at any one time above the first storey or on or above any storey which is at a greater height than twenty feet; or

(*c*) exceeds two storeys in height and contains any storey which is at a greater height than twenty feet and—

(i) is let in flats or tenements; or

(ii) is used as an inn hotel boarding house hospital nursing home boarding school children's home or other institution; or

(iii) is used as a restaurant shop store or warehouse and has on any storey above the ground storey any sleeping accommodation; or

(*d*) contains a place of assembly having a superficial area of not less than five hundred square feet;

It is further provided in the Section, however, that in the cases of a building of the class referred to in sub-paragraph (i) of paragraph (*a*) and of a building of the class referred to in paragraph (*c*) the Council are not entitled to require means of escape from a storey which is not at a greater height than 20 ft., unless the building in question belongs also to one of the other classes mentioned in the Section.

Section 36 contains requirements for the improved construction of the flat roofs of projecting shops, so as to limit the fire risk of persons above the ground storey in the main building; Section 38 requires adequate safeguards and ready means of escape in buildings used for the storage of inflammable liquids; Section 37 requires every building within the scope of Section 36, and every other old building not subject to Section 35, except a dwelling-house used exclusively as such by not more than ten persons, to be provided, if it has a storey at a greater height than 20 ft., with proper means of access to the roof.

EXEMPTIONS FROM ESCAPE REQUIREMENTS. These are set out in Section 150, which contains a list of buildings that are unconditionally exempt, and some that are exempt subject to conditions. Among the latter is a building used to the extent of not less than three-fourths of its cubical extent as a bank or insurance office by not more than two companies or firms, and used as regards the remainder of its extent as living or sleeping accommodation for employees of such companies or firms.

Dangerous Structures. Part VII of the London Building Act, 1939, prescribes the procedure of be adopted by the County Council in the case of dangerous structures. The routine in cases to this kind is for the district surveyor to be asked by the County Council to survey any alleged dangerous structure, and issue his certificate as to its condition. If he certifies that a structure is dangerous the County Council serves a notice on the owner, requiring it to be taken down, repaired, or otherwise secured. The owner then, if he disputes the necessity of any of the requisitions comprised in the notice, may, within seven days, demand that the dispute be referred to arbitration. Should the owner not do the work, or demand arbitration, the County Council may apply to a magistrate for an Order requiring the removal of the danger, or, if the danger is immediate, it may itself take steps to remove the danger. In the City of London, this

Part of the 1939 Act is administered by the City Corporation.

Giving of Notices and Submission of Plans. In the case of all building work in the County of London, including all works of repair affecting the stability or construction of a building. it is necessary to notify the district surveyor. This is enacted in Section 83 of the 1939 Act as follows—

Save as otherwise expressly provided in the London Building Acts a builder shall—

(*a*) when a building or structure or work is about to be begun then two clear days before it is begun; and

(*b*) when a building or structure or work is after having been begun suspended for any period exceeding three months then two clear days before it is resumed; and

(*c*) when during the progress of a building or structure or work the builder employed thereon has been changed then two clear days before the new builder begins work thereon;

serve on the district surveyor a notice (in this Act referred to as a "building notice") respecting the building or structure or work which notice shall comply with the provisions of section 84 (Contents of building notices information as to cost &c) of this Act and all works in progress at the same time to in or upon the same building or structure may be included in one building notice:

Provided that any act or work which by reason of emergency requires to be begun or done immediately or before the building notice relating thereto can be given may be begun or done but the building notice shall be served on the district surveyor not more than twenty-four hours after the act or work has been begun.

Under By-law 154 of the General Building By-laws, dealt with in Chapter VII, the building notice to be served on the district surveyor is to be accompanied, in the case of the erection of a building, by plans showing the construction, together with a copy of the calculations of the loads and stresses. In the case of alterations such plans and calculations as the district surveyor may reasonably require are to be submitted.

Plans must also be submitted to the County Council, the local borough council, and in the City to the City Corporation, in respect of all matters within the control of these authorities.

Appeals. FROM DISTRICT SURVEYOR TO COUNTY COUNCIL. Section 86 of the 1939 Act gives a dissatisfied person the right of appeal from the district surveyor to the County Council. This is enacted in sub-section 1 as follows:—

86.—(1) Save as otherwise expressly provided in the London Building Acts where in those Acts or in any byelaws made in pursuance of those Acts it is provided that any matter or thing shall be or any work shall be carried out to the satisfaction or subject to the approval of or shall be certified by the district surveyor the builder or owner concerned if dissatisfied with any decision or requirement of a district surveyor made under the said Acts or byelaws (other than in the case of any provision that any work shall be carried out to the satisfaction of the district surveyor in a proper and workmanlike manner) may apply to the Council to determine the question.

TO TRIBUNAL. Throughout the London Building Acts, there are many cases in which there is the right of appeal to the Tribunal of Appeal. Among these are appeals against a district surveyor's refusal to certify plans under Sections 13 and 46 of the 1930 Act; an appeal against the superintending architect's definition of the general line of buildings under Section 22 of the 1930 Act; an appeal against a district surveyor's requirement regarding the construction of a public building under Section 26 of the 1939 Act; and appeals against decisions of the County Council regarding formation of streets, erection of buildings within the prescribed distance in narrow streets, erection of buildings of greater height than that laid down in Section 51 of the 1930 Act, the provision of means of escape in case of fire, and various other matters. The constitution and powers of the Tribunal are set out in Sections 109 to 120 of the 1939 Act.

The constitution is as follows: from a panel of six persons, one nominated by a Secretary of State, one each by the four principal professional societies dealing with building work, and one by the association representing the London builders, three persons are to be selected, one of whom must be the person nominated by the Secretary of State, to hear each particular appeal.

The Tribunal are required to keep at the County Hall a register of their decisions on appeals, and this register is open to public inspection.

Chapter VII—THE LONDON BY-LAWS

UNTIL comparatively recently the scope of the by-laws in London was restricted to drainage and sanitation and to the quality of certain building materials. A great change took place in January, 1938, when most of the requirements of the London Building Act, 1930, in regard to the construction of buildings were replaced by by-laws, and new requirements dealing with the use of timber came into force. There are now four sets of by-laws which deal respectively with:—(1) general construction, (2) the use of timber, (3) drainage, (4) water-closets, urinals, earthclosets, etc. The last two do not apply in the City, in which area there are special sets dealing with drainage and sanitary work.

The four sets of by-laws may be obtained from any bookseller, or from Messrs. P. S. King and Son, 14 Great Smith Street, Victoria Street, Westminster, S.W.1, agents for the sale of the County Council's publications. The prices are very small, and total only a few shillings. The four sets comprise a total of fifty-six closely printed foolscap pages, and all that can be attempted here is to give a general analysis, with particulars of the main requirements. In all matters of importance the text of the by-laws should be consulted.

All the by-laws are liable to be revised from time to time. An extensive revision of the General Building By-laws will probably take place shortly, and in this it is possible that the numbering of the by-laws may be altered.

GENERAL BUILDING BY-LAWS

Title. This is given at the head of the official copy as follows:—By-laws for the construction and conversion of buildings and furnace chimney shafts, made by the London County Council in pursuance of the London Building Act (Amendment) Act, 1935.

Subject-matter. The by-laws deal in detail with all matters affecting the construction of buildings, except (*a*) timber construction, (*b*) drainage, and (*c*) sanitary fittings.

Council's Power of Waiver. The administration of the by-laws is less rigid than that of provincial by-laws made under the Public Health Acts, because the Council has the power, on receipt of an application, to modify or waive any by-law. This power is set out in Section 9 of the London Building Act (Amendment) Act, 1935. The Council is required to keep at the County Hall a register of all decisions under this section modifying or waiving the requirements of any by-law, and this register is open to public inspection.

Grouping of Building By-laws. The by-laws are preceded by a list of definitions headed "Interpretation," and are grouped as follows—

Part I: Loading
Part II: Materials of Construction.
Part III: Foundations and Sites of Buildings.
Part IV. Walls and Piers.
Part V: The Use of Structural Steel.
Part VI: The Use of Reinforced Concrete.
Part VII: The Construction of Chimney Shafts.
Part VIII: Miscellaneous.
Part IX: General.

Part I: Loading. Loads are dealt with under two heads: dead loads and superimposed loads; the definitions are as follows—

"Dead loading" means the weight of all walls, floors, roofs, partitions and other like permanent construction.

"Superimposed loading" means all loading other than dead loading.

By By-law 2 every part of a building is to be so constructed as to be capable of safely sustaining all dead and superimposed loads without exceeding the permissible stresses laid down in the by-laws. By-law 4 provides that the minimum superimposed loads shall be estimated as equivalent to the following dead loads:—

In the official copy of the by-laws the loads given in Class Nos. 4, 5 and 6, are prefaced by the words "Loading to be provided for to be ascertained to the satisfaction of the district surveyor, but not less than—"

Class No.	Type of Building or Floor	Slabs: lb. per sq. ft. of Floor Area	Beams: lb. per sq. ft. of Floor Area
1	Rooms used for residential purposes; and corridors, stairs and landings within the curtilage of a flat or residence . . .	50	40
2	Offices, floors above entrance floor	80	50
3	Offices, entrance floor and floors below entrance floor, retail shops; and garages for private cars of not more than two and one quarter tons net weight.	80	80
4	Corridors, stairs and landings not provided for in Class 1. .	100	100
5	Workshops and factories; and garages for motor vehicles other than private cars of not more than two and one quarter tons net weight.	150	120
6	Warehouses, book stores, stationery stores and the like . .	200	200
7	Any purpose not herein specified	Loading to be provided for to be ascertained to the satisfaction of the district surveyor.	

Superimposed loads on roofs vary in accordance with the form of the roof, whether flat or pitched, as follows—

Roofs	Slabs: lb per sq. ft of covered area	Beams. lb per sq. ft. of covered area
Flat-roofs and roofs inclined at an angle with the horizontal of not more than twenty degrees.	50	30

On roofs inclined at an angle with the horizontal of more than twenty degrees a minimum superimposed load (deemed to include the wind load) of fifteen pounds per square foot of surface shall be assumed acting normal to the surface inwards on the windward side, and ten pounds per square foot of surface acting separately and not simultaneously outwards on the leeward side This requirement shall apply only in the design of the roof construction, and a vertical superimposed load of ten pounds per square foot of covered area shall be substituted for it in estimating the vertical superimposed roof load upon all other parts of the construction

In the case of floors it is provided that where the positions of partitions are not definitely located in the design, a uniformly distributed dead load sufficient to allow for them should be added to the dead floor load; in the case of offices this load is stated to be 20 lbs. per sq. ft. of floor area.

The remainder of Part I contains particulars of uniformly distributed loads that slabs and beams, otherwise unloaded, must be capable of safely sustaining; it deals with the permissible reduction of superimposed floor loads in the calculation of the loads on the lower columns and foundations of residential and office buildings; and it also deals with the calculation of the resistance of buildings to horizontal wind pressure, which is to be taken as not less than 15 lbs. per sq. ft. on the upper two-thirds of the surface of a building.

Part II: Materials of Construction. All the ordinary building materials are controlled as regards soundness and quality. Where a material is fully covered by a British Standard Specification, the by-laws require compliance with such specification.

Steel sheets for roofing are to be adequately protected from corrosion, and are to be not less in thickness than No. 24 Birmingham Wire Gauge; this is the same as No. 24 S.W.G.

AGGREGATES FOR CONCRETE. These are dealt with in By-laws 9, 10 and 11; By-law 9, in which the aggregates are termed coarse and fine, deals with the aggregates for reinforced concrete; By-laws 10 and 11, in which the fine aggregate is termed sand, deal with the aggregates for plain concrete. The text of these important by-laws is as follows—

9. The following provisions shall apply to the aggregates for reinforced concrete:—

Aggregate shall be sand and gravel, or crushed natural stone. It shall be hard strong and durable

and shall be reasonably clean and free from clay, organic matter, coal and coal residues (including clinker, ashes, coke-breeze, pan-breeze, slag and other similar material), copper slag, forge breeze, dross (and other similar material), soluble sulphates (including gypsum and other similar material), porous material and other materials liable to reduce the strength or durability of the concrete, or to attack the steel reinforcement.

Fine aggregate shall be of such a size that it will pass through a $\frac{3}{16}$-inch mesh. Not more than five per cent. by weight shall pass a No. 100 mesh.

Coarse aggregate shall be of such a size that it will be retained on a $\frac{3}{16}$-inch mesh and will pass a mesh of a size one-quarter of an inch less than the minimum lateral distance between the reinforcing bars.

Aggregate shall be so graded between the limits as to make a dense concrete of the specified proportions and consistence that will work readily into position without segregation and without the use of an excessive water content.

10. Aggregate for plain concrete shall consist of such materials as are specified in by-law 9 or of hard well-burned brick, hard well-burned tile, pumice or other material which the district surveyor may approve as of like suitability and shall be so graded and contain sand in such proportion as to produce a dense concrete.

11. Sand shall be clean and shall be composed of hard silicious grains reasonably free from clay or any animal, vegetable or bituminous matter. The grains shall be of such a size as to pass through a $\frac{3}{16}$-inch mesh.

PROPORTIONING OF MATERIALS FOR CONCRETE. This subject is dealt with by means of tables in which are given various mixes according to the nature of the work involved, the cement being given in terms of weight and the aggregate in terms of volume. The tables are shown below.

All grades of concrete are to have a crushing strength not less than that given in column 3; work tests are to be made if required by the district surveyor in the case of the grades in Table I, and both preliminary and works tests if so required in the cases of the grades in Table II. The methods of making the tests are given in schedules at the end of Part II. Grades I, II, and III in Table I are termed "ordinary concrete" and grades IA, IIA, and IIIA, in Table II are termed "Quality A concrete." The grades in Table II are specially suitable for high class reinforced concrete. Grades I, II and III in Table I are suitable for reinforced concrete and for plain concrete which is required to be of

TABLE I

(1)	(2)		(3)
Designation of Concrete	Cubic feet of aggregate per 112 lbs of cement		Minimum resistance to crushing in lbs. per square inch within 28 days after mixing
	Fine aggregate	Coarse aggregate	
I	$1\frac{1}{4}$	$2\frac{1}{2}$	2,025
II	$1\frac{7}{8}$	$3\frac{3}{4}$	2,550
III	$2\frac{1}{2}$	5	2,250
IV	$7\frac{1}{2}$		1,480
V	10		1,110
VI	$12\frac{1}{2}$		740
VII	15		370

TABLE II

(1)	(2)		(3)	
Designation of concrete	Cubic feet of aggregate per 112 lbs of cement		Minimum resistance to crushing in lbs. per square inch within 28 days after mixing	
	Fine aggregate	Coarse aggregate	Preliminary test	Works test
IA	$1\frac{1}{4}$	$2\frac{1}{2}$	5,625	3,750
IIA	$1\frac{7}{8}$	$3\frac{3}{4}$	4,950	3,300
IIIA	$2\frac{1}{2}$	5	4,275	2,850

more than usual strength; Grades IV and V are suitable for ordinary foundation concrete; the use of Grades VI and VII is permissible only in the case of concrete filling.

MORTAR. This is dealt with in By-law 17 as follows—

17. Cement mortar shall be composed of cement mixed with sand or other material approved as of like suitability by the district surveyor, in the proportions of one part of cement to not less than two, nor more than four, parts of the sand or other such material measured by volume.

Cement-lime mortar shall be composed of Portland cement and hydrated lime mixed with sand or other material approved as of like suitability by the district surveyor. The proportions of cement and lime shall be as one volume of cement to not less than one, nor more than five volumes of hydrated lime. The proportions of the cement-lime mixture to the sand (or other approved material) shall be as one volume of cement-lime mixture to not less than two, nor more than four volumes of sand (or other approved material).

Lime-mortar shall be composed of putty from commercial hydrated lime or properly slaked sieved and matured lime mixed with sand or with other material approved as of like suitability by the district surveyor. The proportions of lime to sand (or other approved material) shall be as one volume of such slaked lime or putty to not less than two and not more than four volumes of sand or other material approved as of like suitability by the district surveyor.

STONE AND BRICKS. Stone is required to have a crushing strength of not less than 1,500 lbs. per sq. in. Bricks are required to have crushing strengths in accordance with Table III (not reproduced). These vary from 10,000 lbs. per sq. in. in the case of special bricks to 1,500 lbs. per sq. in. in the case of 6th quality bricks.

PLASTERING. The materials for plastering are set out in By-law 24 as follows—

24. Lathing for plastering shall be of sound well-seasoned wood free from sap, or of suitable metal lathing or of other material of like suitability.

The filler for plastering shall consist of sand or other material of like suitability.

The binding material for plastering shall consist of putty from commercial hydrated lime or of properly slaked, sieved and matured lime, or of cement, calcium sulphate plaster or of other material of like suitability, or of either cement or calcium sulphate plaster in suitable combination with commercial hydrated lime or properly slaked, sieved and matured lime.

The materials for rendering and floating coats of plastering shall consist of filler and binding material and the proportion of filler to each volume of lime or cement shall be not less than two and not more than four volumes, and to each volume of calcium sulphate plaster not less than one and not more than three volumes. If the district surveyor so requires, there shall be mixed with every three cubic feet of such plastering, one pound of good sound clean well-beaten hair or other fibrous material of like suitability.

The materials for setting coats of plastering shall consist of sound lime putty and filler, or cement and filler, or a combination thereof, or of calcium sulphate plaster with or without the addition of sound lime putty or filler, or of any combination of materials approved by the district surveyor.

A subsequent coat of plastering shall not be applied until the previous coat has thoroughly dried.

If fibrous slab or other slab or sheet plastering is employed, it shall be of sufficient thickness and shall be securely fixed

Part III: Foundations and Sites of Buildings. The principles governing foundation work are set out in By-law 26 as follows:—

Every foundation shall be constructed to sustain and transmit safely all the loading imposed thereon, and without exceeding the limitations of permissible stresses provided in these by-laws.

Piling shall be to the satisfaction of the district surveyor.

Soil pressure is dealt with in By-law 30 which provides that the pressure to support any part of a building shall be calculated if so required by the district surveyor, and that the intensity of pressure shall not exceed that allowed by the district surveyor. In this by-law there is a foot-note (not part of the by-law) stating that the following loads are given as a general guide to the safe bearing capacity of various sub-soils—

	Load on ground. Tons per sq. ft.
Alluvial soil, made ground, very wet sand	½
Soft clay, wet or loose sand	1
Ordinary fairly dry clay, fairly dry fine sand, sandy clay	2
Firm dry clay	3
Compact sand or gravel, London blue or similar hard compact clay	4

By-laws 27 to 29 deal with the sites of buildings and require all faecal or other offensive matter to be removed, unless it has become or been rendered innocuous, and all excavations, voids or cavities in the site and within a distance of 3 ft. from the external face of the enclosing walls to be filled in with concrete or such other material as the district surveyor may approve. Concrete for filling is not to be inferior to that designated VII in Table I.

The site of every building is to be covered with concrete not inferior to that designated V in Table I, not less than 6 in. thick, and smoothed on the upper surface; if reinforced concrete is used the minimum thickness is 4 in.

By-law 33 provides that every wall or pier, unless supported on a beam, shall rest on concrete. The concrete is required normally to have a projection on each side not less than the thickness of the wall or pier at the base, the

width of the concrete being thus three times the thickness of the wall or pier, but the district surveyor has power to allow a lesser width, if he is satisfied that the standard of stability is not impaired. Brick footings may be provided, but are not required by the by-laws. The angle of dispersion of a load through plain concrete must not be taken as less than 45 degrees with the horizontal; so the thickness of a plain concrete foundation must at least equal the projection. The thickness of a so-called 9 in. wall is usually $8\frac{1}{2}$ in., so the minimum width of a plain concrete foundation for such a wall is $3 \times 8\frac{1}{2} = 25\frac{1}{2}$ in. $= 2$ ft. $1\frac{1}{2}$ in., and the minimum thickness of the foundation $8\frac{1}{2}$ in.

MAXIMUM PRESSURES ON PLAIN CONCRETE. These are required by By-laws 34 and 35 not to exceed those given in Table IV for filling and in Table V for foundations in which the ratio of height to least width does not exceed 2. The tables are as follows—

TABLE IV

Designation of Concrete	Maximum permissible intensity of pressure in tons per square foot
IV	20
V	15
VI	10
VII	5

TABLE V

Designation of Concrete	Maximum permissible intensity of pressure in tons per square foot
I	40
II	35
III	30
IV	20
V	15

There is also Table VI (not reproduced) which gives maximum pressures on plain concrete when the ratio of height to least horizontal dimension exceeds 2, as is sometimes the case when "legs" of concrete are carried down through soft soil to a hard bottom.

Part IV: Walls and Piers. This is arranged in three portions as follows (the official section-headings being summarized in two cases)—Section 1, General Requirements; Section 2, Wall Thicknesses when not Calculated; Section 3, Calculated Walls and Piers.

GENERAL REQUIREMENTS. These apply to all walls, whether calculated or otherwise. By-law 39 contains the general rules for the maximum sizes of openings in walls, there being, however, a further limitation in the case of non-calculated walls as set out in By-law 51 (*g*). The text of By-law 39 is as follows—

Every building shall be enclosed with walls. Provided that openings may be made in such walls subject to the following conditions—(1) That the total elevational area of openings in any such wall above the soffit of the first floor do not exceed one-half the elevational area of such wall measured from the soffit of the first floor of the building to the roof, (2) that the total elevational area of openings in any storey-height of such wall above the soffit of the first floor of the building do not exceed two-thirds of the total area of such wall within such storey-height; (3) that the total width of openings at any level above the soffit of the first floor do not exceed three-quarters of the total length of the wall at that level For the purposes of this by-law, the expression "walls" shall be deemed to include piers and for the purpose of this by-law and of By-laws 43 and 51 (*g*) any glazing or glass in the thickness of such walls shall be deemed to be an opening.

MINIMUM THICKNESSES OF WALLS. The requirements on this subject are contained in By-law 43 and may be summarized as follows—

External or buttressing walls of bricks or blocks or plain concrete $8\frac{1}{2}$ in.

External walls of reinforced concrete 4 in.

Party walls of reinforced concrete 8 in.

Party walls of ordinary construction except in the case of walls of less than certain heights given in detail in the by-law, are required to have a minimum thickness in every part of not less than $13\frac{1}{2}$ in.

There are certain exceptions to these rules in the case of small buildings. These are set out in the by-law as follows—

Provided that—

(i) a building of not more than one storey in height, not being a dwelling house, and the width of which (measured in the direction of the span of the roof) does not exceed thirty feet and the height of the walls of which does not exceed ten feet, or

(ii) an erection situated above the level of the roof of a building and intended for the protection of a tank or motor or for a like purpose, and not intended for or adapted to use for habitable purposes or as a work room, such erection being adequately supported to the satisfaction of the district surveyor, and not exceeding ten feet in either length or width and not exceeding eight feet in height measured from the level of the roof of the building to the top of the walls of such erection;

may be enclosed with external walls constructed of bricks or blocks and not less than four inches thick subject to the following conditions—

(*a*) That any such wall be bonded into piers of the size required by calculations based on the loads and stresses specified in these by-laws, but not less than eight and one-half inches square in horizontal section.

(*b*) That such pier be provided at each end of such external wall.

(*c*) That in the case of (i) further similar piers be provided if any such wall exceeds ten feet in length, as may be necessary so to divide the wall that the length of each portion of such wall shall not exceed ten feet measured in the clear between such piers.

(*d*) That all bedding and jointing be in cement mortar.

(*e*) That the roof be so constructed that the walls are not subject to any thrust therefrom.

(*f*) That no load other than a distributed load of the roof be borne by the walls.

CAVITY WALLS. By-law 45 deals with cavity walls, the leaves of which are required to be not less than 4 in. thick, and to be united by iron ties. The width of the cavity is to be not less than 2 in. and not more than 6 in. The number and spacing of the ties depend on the width of the cavity. The maximum height for non-calculated cavity walls is stated in By-law 53 (*b*) to be 25 ft., and the maximum length 30 ft.

PREVENTION OF DAMPNESS. This matter is regulated by By-laws 46 and 47. The first mentioned by-law is in general terms as follows:—"Every building is to be so constructed as to ensure that it will not be affected adversely by moisture from adjoining earth." By-law 47 requires that the top of every wall not otherwise protected from the weather shall have a coping.

LIST OF WALL THICKNESSES. The text of the official heading to Section 2 is as follows: "Rules for the determination of the thicknesses of walls when such thicknesses are not determined by calculation of stresses under Section 3." The section contains a list of wall thicknesses of a similar character to the table of wall thicknesses in the Model By-laws, and it is provided that walls may be constructed to these thicknesses so long as they conform to certain conditions termed "the prescribed conditions" which are given in By-law 51, and of which the principal may be summarized as follows:—that the walls are constructed of bricks or blocks properly bonded, or of plain concrete not inferior to Grade IV in Table I, that they do not support more than one storey in the roof, that they are not subject to lateral pressure, and that the total elevational area of openings and recesses in a wall in any storey does not exceed one-half the elevational area of the wall in such storey, this last condition being set out in paragraph (*g*).

Two lists of wall thicknesses (not reproduced) are given in By-laws 54 and 55, one for ordinary buildings, termed "buildings other than public buildings or buildings of the warehouse class," and one for buildings of the warehouse class. The appropriate list requires to be carefully consulted when designing any non-framed building in London. There is no list of thicknesses for the walls of public buildings, this being a matter within the discretion of the district surveyor.

The thicknesses given in the lists are for external and party walls. As regards other walls, it is provided in By-law 53 that a wall buttressing (but not being) an external or party wall is to be not less than two-thirds the specified thickness. The definition of "buttressing wall" in By-law 1 is as follows—

"buttressing wall" means a wall affording lateral support to another wall and—

(*a*) If constructed in accordance with the requirements of Section 2 of Part IV of these by-laws, is of a length equal to not less than one-sixth of its height, and situated at right angles to the wall which is deemed to be buttressed thereby, or of such lesser length or situated at such other angle as calculations in accordance with these by-laws may show to be sufficient to afford adequate lateral support to the wall so deemed to be divided,

(*b*) if constructed otherwise than in accordance with the requirements of Section 2 of Part IV of these by-laws, is so disposed and of such dimensions as calculations in accordance with these by-laws may show to be sufficient to afford adequate lateral support to the wall so deemed to be buttressed thereby;

The required thickness of a wall depends on its length and height. Length is stated in By-law 52 to be the clear dimension between buttressing walls. The height of a wall is defined in By-law 1 as follows—

"Height" in relation to a wall or pier means the vertical dimension measured from the base of such wall or pier to the top thereof, or if the top be shaped as a gable, to midway between the base of the gable and the top thereof.

These rules for the measurement of the length and height of a wall differ materially from the repealed rules of the London Building Act, 1930, in which "length" was stated to be measured between centres of return walls, and "height" was measured from the base of the wall to the top of the topmost storey, irrespective of whether or not the wall was carried up to that height.

PANEL WALLS. These walls are subject to the ordinary rules as to thickness, with the proviso, given in By-law 56, that the height of

a panel is not to exceed 25 ft., and that the height or length (whichever is the less) is not to exceed 18 times the structural thickness.

CALCULATED WALLS. Section 3 comprises detailed rules for the calculation of walls of bricks or blocks and walls of plain concrete. It contains Tables VII and VIII (not reproduced) giving the maximum pressures in the case of various qualities of these materials when used in walls. There were no similar rules in previous legislation. Owing to the newness of the rules, and also to the suspension of most civil building during the war, comparatively little use has been made of this method of design, and little experience has been gained.

UNDERPINNING. This is dealt with in By-laws 57 and 62. In non-calculated walls it is to be of the thickness of the old work or of the required thickness under Section 2, whichever may be the greater. In calculated walls it is to be of such thickness that the permissible stresses given in Section 3 are not exceeded. In all cases the work is to be carried out to the satisfaction of the district surveyor.

Part V: The Use of Structural Steel. The text of this Part should be closely studied by anyone who designs in this material. It should be noted that, while the by-laws regarding the use of steel apply in the first instance to buildings of frame construction, they are by By-law 91 made applicable also to buildings of non-framed construction.

All steel is required to comply with the British Standard Specification relative to its shape, whether in the form of beams, channels, angles, etc. Loads are to be transmitted to the earth by concrete; this if plain is to be not inferior to Grade V in Table I, and if reinforced is to comply with the rules in Part VI. The angle of dispersion of loads through plain concrete is not to be less than 45 degrees with the horizontal.

FABRICATION OF STEELWORK. This is required by By-law 74 to be completed as far as practicable at the works. Welding may be adopted in any particular case only with the consent of the Council, and "in accordance with the conditions prescribed by the Council in that case."

CASING OF STEELWORK. All steelwork, except that in one-storey buildings not exceeding 25 feet in height, is required to be cased. The rules for casing are given in By-law 68 as follows—

(*a*) A steel column or beam wholly or partly in an external wall or wholly or partly within a recess in a party wall shall be completely encased and protected from the action of fire with brickwork, terra-cotta, concrete, stone, tiles or other similar incombustible materials (or suitable combination of such incombustible materials) at least four inches in thickness in compliance with this by-law.

Provided that the casing on the underside of such a beam, and to the edges of the flanges thereof and of plates and angles connected therewith, may be of any thickness not less than two inches.

(*b*) Any other steel column or beam shall be completely encased and protected from the action of fire with brickwork, terra-cotta, concrete, stone, tiles or other similar incombustible materials or any suitable combination thereof approved by the district surveyor at least two inches in thickness in compliance with this by-law.

Provided that the casing on the upper surface of the upper flange of such a beam, and on other parts (such as projecting cleats, projecting rivet-heads and the like) of such a column or beam, may be of any thickness not less than one inch.

This requirement shall not apply in the case of a building which comprises only one storey and is not more than twenty-five feet in height.

(*c*) All casing required for compliance with this by-law shall be executed with Portland cement, and shall be bedded close up to the steel without any intervening cavities All joints in such casing shall be made full and solid.

The by-law applies not only to steelwork in a new building, but also to the steelwork of alterations to an existing building. But in a small alteration to an old building in which none of the steelwork is cased, it is probable that either the casing requirements will not be pressed, or, on application to the Council, a waiver will be granted.

MAXIMUM STRESSES IN STEEL. These as affecting tension members and beams are given in By-law 81, the principal rules being as follows—

	Tons per sq. in.
(*a*) *For parts in tension*	
On the net section for axial stresses or extreme fibre stresses of all beams .	8
(*b*) *For compression flanges of beams.*	
On the gross section for extreme fibre stress of beams embedded in a concrete floor or otherwise laterally secured	8
On the gross section for extreme fibre stress of uncased beams where the laterally unsupported length "L" is less than twenty times the width "b" of the compression flange .	8
On the gross section for extreme fibre stress of uncased beams where "L" is greater than twenty times "b" .	$11.0-0.15\frac{L}{b}$

For beams solidly encased as provided for in By-law 68, the width "b" in the above formula may be taken as the width of the compression flange of the beam plus the lesser side concrete cover beyond the edge of

the flange on one side only with a maximum of four inches.

The ratio $\frac{L}{b}$ shall not exceed 50.

Maximum stresses are also given in the by-law for rivets and bolts in tension, shearing and bearing, and there are rules in By-law 82 which admit of the stresses in grillage beams exceeding by 50 per cent the general rules. By-law 83 provides that the strength of filler joist floors with the steel beams entirely encased in concrete may be calculated as in reinforced concrete with the limit of stress in the steel taken as 9 tons per sq. in.

MAXIMUM SPANS. This is dealt with in By-law 84 as follows—

The span of any filler floor beam encased in concrete shall not exceed thirty-two times the depth measured from the bottom flange of the floor beam to the top surface of the concrete

The span of any other beam shall not exceed twenty-four times its depth unless the calculated deflection of the beam is less than one three hundred and twenty-fifth part of the span.

MAXIMUM STRESSES IN COLUMNS. These are set out in By-law 85 as shown below.

Rules for calculating the effective column length in accordance with the direction and degree of restraint at the top and bottom of the length are given in By-law 86. These rules will require to be consulted, but as a general guide it may be said that in the case of columns continuing through two or more storeys, the column length, if properly restrained at both ends in two directions, may be taken as being three-quarters (0·75) of the height from floor-level to floor-level.

STRESSES DUE TO WIND. By-law 90 provides that the permissible stresses applying in normal cases may be increased in beams and columns by 33⅓ per cent. when the increase is due to wind pressure.

Part VI: The Use of Reinforced Concrete. By-law 92 provides that reinforced concrete is not to be inferior to Grade III in Table I. Loads are to be transmitted to earth by concrete, either plain or reinforced. If plain, the concrete is required by By-law 94 to be not inferior to Grade V in Table I. The angle of dispersion of a load through plain concrete is not to be taken as less than 45 degrees with the horizontal.

CHARACTER AND USES OF STEEL REINFORCEMENT These matters are dealt with in By-law 96 as follows—

Reinforcement shall be of structural steel complying with these by-laws so combined with the concrete that the reinforcement will be sufficient to provide, in accordance with these by-laws, all necessary—

(*a*) resistance to tension,

(*b*) assistance for the concrete to resist shearing actions; and

(*c*) assistance for the concrete to resist compression.

(*a*) The permissible ratio of effective column length to least radius of gyration in a steel column shall not exceed the following values—

(i) For columns and struts forming part of the main structure of a building 150

(ii) For subsidiary members in compression 200

(*b*) The working loads per square inch in the shafts of columns and other compression members of structural steel shall not exceed those specified in the following table, except as provided in By-laws 87 and 90

Ratio of Effective Column Length to least Radius of Gyration $= \frac{l}{r}$	Working loads in tons per square inch of gross section $= F_1$	Ratio of Effective Column length to least radius of gyration $= \frac{l}{r}$	Working loads in tons per square inch of gross section $= F_1$
20	7·2	130	2·6
30	6·9	140	2·3
40	6·6	150	2·0
50	6·3	160	1·8
60	5·9	170	1·6
70	5·4	180	1·5
80	4·9	190	1·3
90	4·3	200	1·2
100	3·8	—	—
110	3·3	—	—
120	2·9	—	—

Intermediate values shall be obtained by interpolation.

Reinforcement shall, immediately before being placed in the concrete, be free from loose mill scale, loose rust, oil or other matter which might affect adversely the proper combination of such reinforcement with such concrete.

PROTECTION OF STEEL. This is dealt with in By-laws 95 and 97. By-law 95 deals with steel reinforcement in foundation work and requires that proper protection to prevent damage to the metal is to be provided to the satisfaction of the district surveyor. By-law 97 deals with the protection of steelwork in all other parts of a building, and lays down rules as follows—

Reinforcement shall have concrete cover, and the thickness of such cover (exclusive of plaster or other decorative finish) shall be—

(*a*) for each end of a reinforcement rod or bar which is anchored otherwise than by means of a hook, not less than 2 inches, nor less than twice the diameter of such rod or bar beyond such anchorage,

(*b*) for a longitudinal reinforcement rod or bar in a column, not less than 1½ inches, nor less than the diameter of such rod or bar,

(*c*) for a longitudinal reinforcement rod or bar in a beam, not less than 1 inch, nor less than the diameter of such rod or bar,

(*d*) for tensile, compressive, shear or other reinforcement in a slab, not less than half an inch, nor less than the diameter of such reinforcement;

(*e*) for any other reinforcement (not being a binding), not less than half an inch, nor less than the diameter of such reinforcement

SCOPE OF REINFORCED CONCRETE REQUIREMENTS. By-law 98 provides that By-laws 99 to 112 relate only to the use of reinforced concrete in framed buildings, but this rule must be read in conjunction with the rule in By-law 113, where it is stated that, in the case of non-framed buildings in which reinforced concrete is used, the standard of stability is to be to the satisfaction of the district surveyor, and is not to be inferior to that required for compliance with By-laws 99 to 112.

STRESSES IN CONCRETE. By-law 99 provides that the compressive shearing and bond stresses in concrete shall not exceed those given in the Tables shown below.

The by-law also provides that the limit of "punching shear" in a footing or similar construction is twice that for ordinary shear.

STRESSES IN STEEL. The limits of stresses in steel reinforcement are given in Table XI as shown on page 1683.

STRENGTH OF COLUMNS. This is dealt with in By-law 101 which provides that the maximum permissible stresses in a column having a ratio of effective column length to least radius of gyration not exceeding 50 are those given in Tables IX, X, and XI. Where this ratio is more than 50 the stresses are not to exceed those which result from multiplying those in the

TABLE IX—*Ordinary Concrete*

Designation of Concrete	Modular Ratio	Permissible Concrete Stresses lbs per square inch			
		Compression		Shear	Bond
		Due to Bending	Direct		
I	15	975	780	98	123
II	15	850	680	85	110
III	15	750	600	75	100

TABLE X—*Quality A Concrete*

Designation of Concrete	Modular Ratio	Permissible Concrete Stresses lbs. per square inch			
		Compression		Shear	Bond
		Due to Bending	Direct		
IA	15	1,250	1,000	125	150
IIA	15	1,100	880	110	135
IIIA	15	950	760	95	120

TABLE XI

Designation of Stress in Steel Reinforcement	Maximum Permissible Stress, in pounds per square inch
Tension in helical reinforcement in a column	13,500
Tension other than in helical reinforcement in a column	18,000
Longitudinal compression in a beam where the compressive resistance of the concrete is not taken into account	18,000
Longitudinal compression, direct or due to bending where the compressive resistance of the concrete is taken into account	The calculated compressive stress in the surrounding concrete multiplied by the modular ratio.

Tables by the coefficient given in Table XII, which is as follows—

TABLE XII

Ratio of effective column length to least radius of gyration	Coefficient.
50	1·0
60	0·9
70	0·8
80	0·7
90	0·6
100	0·5
110	0·4
120	0·3

No reinforced concrete column is to have a ratio of effective length to least radius of gyration of more than 120.

The rules for determining the effective column length are given in By-law 102. These provide that in the case of a column continuing through two or more storeys, the column length, if properly restrained at both ends in two directions, may be taken as three-quarters (0·75) of the distance from floor-level to floor-level.

STRESSES DUE TO WIND. Under By-law 103 the stresses in Tables IX, X, and XI, may be exceeded by $33\frac{1}{3}$ per cent when such excess is due to wind pressure. This permissible increase does not, however, apply to secondary floor beams or to roof construction above the level of the topmost floor.

MAXIMUM AND MINIMUM SIZES OF REINFORCEMENT. These are given in By-law 106 as follows—

The diameter of a steel reinforcement in reinforced concrete shall be not more than 2 inches.

The diameter of a longitudinal steel reinforcement in a reinforced concrete column shall be not less than $\frac{1}{2}$ inch.

The diameter of a main steel reinforcement in a reinforced concrete beam or slab shall be not less than $\frac{1}{4}$ inch

The diameter of a steel reinforcement in reinforced concrete other than a longitudinal reinforcement in a column or a main reinforcement in a beam or slab, and the diameter of steel forming a tie, helix, stirrup or the like, shall be not less than $\frac{3}{16}$ inch.

The diameter of steel forming a mesh-reinforcement for the purpose of resisting tension in reinforced concrete shall be not less than $\frac{1}{10}$ inch.

REINFORCEMENT FOR COLUMNS. By-law 104 gives the minimum and maximum percentage of reinforcement in columns as follows—

A reinforced concrete column shall have longitudinal steel reinforcement, and the cross-sectional area of such reinforcement shall not be less than 0·8 per cent., nor more than 8 per cent., of the gross cross-sectional area of the column required to transmit all the loading in accordance with these by-laws.

A reinforced concrete column having helical reinforcement shall have also at least six bars of longitudinal reinforcement within such helical reinforcement. Such longitudinal bars shall be in contact with such helical reinforcement and equidistant around its inner circumference

At a splice in a longitudinal reinforcement, the spliced bars shall overlap longitudinally through a distance not less than 24 times the diameter of the upper bar, or a sufficient distance to develop the force in the bar by bond, whichever is the lesser.

By-law 105 gives the following rules for the sizes and pitch of transverse reinforcement in columns (usually termed links or hoops).

The diameter of such transverse reinforcement shall be not less than one-fourth of an inch.

The pitch of such transverse reinforcement shall be not more than the least of the three following distances—

(1) the least lateral dimension of such column;
(2) twelve times the diameter of the smallest longitudinal reinforcement in such column;
(3) 12 inches.

The by-law also gives rules for the pitch of helical reinforcement.

DISTRIBUTING BARS IN SOLID SLABS. The following rules are given in By-law 110—

A reinforced concrete solid slab spanning in one direction shall have distributing bars at right angles

to the main tensile reinforcement of such slab; and the aggregate cross-sectional area of such distributing bars shall be not less than one-tenth of the aggregate cross-sectional area of such main tensile reinforcement associated therewith.

It is also provided in By-law 107 that the pitch of distributing bars shall not be more than 4 times the effective depth of the slab.

ANCHORAGE OF COMPRESSIONAL REINFORCEMENT IN BEAMS. By-law 111 provides that the stirrups or similar reinforcement used for this purpose shall pass round or be hooked over both the compression and tensile reinforcement, and that the spacing shall not exceed twelve times the diameter of the anchored bar when the compressive resistance of the concrete is taken into account, and eight times such diameter when the compressive resistance is not taken into account.

SPECIAL CONSENT NECESSARY FOR WELDING. By-law 114 provides that reinforcement is not to be connected by welding "except in accordance with conditions prescribed by the Council in each particular case." The bars of mesh reinforcement not exceeding 0·4 in. diameter may, however, be welded at their points of contact, subject to the district surveyor being satisfied with the suitability of the reinforcement for treatment in this manner.

Part VII: Construction of Chimney Shafts. This Part is not easy to understand at first glance. For it begins in By-law 119 with a definition of "chimney shaft" which extends the usual conception of the term to the material surrounding any flue which exceeds 80 sq. in.—that is to say any flue which is larger than what is usually termed a 9 in. × 9 in. flue, which is usually about $8\frac{3}{4}$ in. × $8\frac{3}{4}$ in. in area. This definition makes the general requirements of Part VII a little confusing, as the chimney stacks which by reason of the definition are included in the term "chimney shaft" are not those which require to be built with a batter as mentioned in By-law 25, and are not the kind of shafts which appear to be contemplated in the provisions of some of the other by-laws.

It should be appreciated that the Part deals in effect with two forms of brick shafts, namely (*a*) the large shaft which is practically detached, being connected with a building only by a horizontal flue at the base, and (*b*) the shaft which forms part of a building, and which if large is usually built on the outside face of one of the external walls, and if small is usually built on the inside face of a wall. By-laws 120 to 131 deal with shafts (*a*); in the case of shafts (*b*) it is provided in By-law 119 that a shaft of this type may be constructed in such manner as the district surveyor may approve, subject to—

(*a*) the standard of stability being not inferior to that required by By-laws 120 to 131 (inclusive); and

(*b*) proper precautions being taken to prevent damage to the building through heat or through corrosion of structural steel.

DETAILED RULES. By-laws 120 to 130 deal in detail with the construction of a large shaft, including its foundation. Such by-laws give the limits of height in relation to the width at the base, the minimum batter or inclination, and the minimum thickness of brickwork, which is $8\frac{1}{2}$ in. for the top 20 ft., increased by at least one half-brick for every additional 20 ft. or part of 20 ft., measured downwards. By-law 131 requires that any internal lining is to be in addition to and independent of the enclosing brickwork.

Part VIII: Miscellaneous. Requirements of various kinds are included as follows—

By-laws 132 to 134: chimneys, flues and hearths.
,, 135: gas heated geysers.
,, 136: flue pipes.
,, 137 to 139: party structures, arches and floors over and under passages and public ways, and floors above furnaces or ovens.
,, 140 and 144: requirements which apply in the case only of buildings of a certain size and character (already dealt with in Chapter VI).
,, 141 and 149: height and ventilation of rooms, and separation of rooms from certain other parts of a building.
,, 142: woodwork in external walls.
,, 143: projections from buildings.
,, 145: parapets to external walls.
,, 146: parapets to party walls.
,, 147: roof coverings.
,, 148: limitation of number of storeys in roof, and required fire-resisting construction of storeys more than 60 ft. above street level.
,, 150: required fire-resisting construction of floors and staircases in steel-frame and reinforced concrete buildings.

Mention is made below of some of the more important of these requirements.

Flues for fires burning solid fuel are not to be less than $7\frac{1}{2}$ in. × $7\frac{1}{2}$ in.; flues for gas fires are not to be less than 20 sq. in. The brickwork or other material surrounding flues is not to be of less thickness than 4 in. in the case of the first-mentioned flues and not less than 1 in. in the case of gas flues. Flues from trade boilers or close fires, and from trade ranges or other cooking apparatus are required by Clause 3 of By-law 133 to be surrounded with brickwork $8\frac{1}{2}$ in. thick for the height of two storeys. A chimney stack from an ordinary fire is to be carried up to a height of at least 3 ft. above the roof, that from a gas fire to a height of at least 18 in. The top six courses of every chimney stack are to be built in cement mortar. Hearths are to be of solid incombustible material not less than 6 in. thick; the sizes of hearths vary in accordance with the type of fire

Every arch or floor which is a party structure and every arch or floor over or under a passage leading to other premises, or over or under a public way is required to be of incombustible material of an aggregate thickness of not less than 5 in. There are also rules in By-law 137 for partitions which are party structures. The term party structure is defined in Section 4 of the London Building Acts (Amendment) Act, 1939, as follows—

"Party structure" means a party wall and also a floor partition or other structure separating buildings or parts of buildings approached solely by separate staircases or separate entrances from without.

HEIGHT AND VENTILATION OF ROOMS. Rooms used for the purpose of an office or for habitation are required by By-law 141 to be 8 ft. 0 in. high if in the topmost storey, and 8 ft. 6 in. high elsewhere. A topmost room wholly or partly in the roof complies with the requirements if it is 8 ft. high throughout half its area when such area is measured at a level of 3 ft. above floor-level.

It should be noted that the minimum height of rooms below the topmost storey is 6 in. more than that given in the Model By-laws, and that the requirement extends to rooms used as offices.

By-law 141 deals also with the separation of a garage or stable from any room used for the purpose of an office, factory, workshop or workroom or for habitation. The required vertical separation is by walls at least $8\frac{1}{2}$ in. thick, with any openings fitted with fire-resisting self-closing doors; the horizontal separation is to be either by an incombustible floor or by a wood floor with pugging not less than 3 in. thick. The ceiling on the underside of a wood floor is to be of lath and plaster in the case of a stable, and asbestos cement sheeting in the case of a garage.

By-law 149 deals with the lighting and ventilation of rooms, and requires every room used for the purposes of an office or for habitation to have a window of a superficial area, clear of the frames, sashes and sash bars, at least equal to one-tenth of the floor area, with a portion at least equal to one-twentieth of the floor area formed to open. A room without a fireplace is required to have an aperture or air-shaft, communicating either with the open air or with a ventilated lobby or corridor.

PARAPETS TO EXTERNAL AND PARTY WALLS. By-law 145 provides that where a gutter next an external wall is formed of combustible materials the wall shall be carried up to form a parapet $8\frac{1}{2}$ in. thick and 12 in. in height above the highest part of the gutter.

The general rules for the carrying up of party walls are set out in the first portion of By-law 146 as follows—

(1) Every party wall shall be carried up above the roof flat or gutter as the case may be of the highest building adjoining the wall in such manner that:—

(a) the thickness of the part of the wall so carried up—

(i) in the case of any building of the warehouse class is equal to the thickness of the top of the wall as required by these by-laws; or

(ii) in the case of any other building is eight and a half inches; and

(b) the distance measured either from the roof at right angles to the slope thereof or vertically from the level of the highest part of the flat or gutter as the case may be to the top of the said part of the wall—

(i) in the case of any building of the warehouse class exceeding thirty feet in height is at least three feet; or

(ii) in the case of any other building is at least fifteen inches.

The by-law provides, however, that the requirements do not apply where the roofs abutting on a party wall are of incombustible material, nor to a case where the difference in height of the roofs on each side of the party wall exceeds 3ft., nor in the following two other cases—

(a) in the case of a row or terrace not exceeding 150 ft. in length of two-storey dwelling-houses not exceeding eight in number, if no combustible parts of the roofs are

carried across the party walls, and the roof covering is solidly bedded in mortar on the tops of the walls.

(*b*) in the case of a party wall between two domestic buildings (i.e. buildings which are not public buildings or of the warehouse class) if the wall is provided at the top with an oversailing slab of incombustible material not less than 4 in. thick, supported on each side by brick corbelling and projecting not less than 9 in. beyond each face of the wall, with no combustible parts of the roof carried across the slab, and with the roof covering solidly bedded in mortar on the slab for the whole of its width.

ROOF COVERINGS AND ROOF PITCHES. Roofs are required by By-law 147 to be covered externally with slates, tiles, metal or other incombustible material. Provision is also made in the by-law for the covering of flat roofs and roofs with a pitch not exceeding 20 degrees with asphalt or bitumen macadam. The maximum pitch of a roof is 75 degrees, and in the case of a building of the warehouse class of which the roof is not constructed entirely of incombustible material the maximum of pitch is 47 degrees.

Part IX: General. This Part deals with the question of administration, and also contains a list of the requirements that have been repealed and replaced by by-laws. By-law 152 deals with conversion and states that a building or part of a building is not to be converted in such manner that the building or part, when converted, is not in accordance with the by-laws. It should be noted that in Section 139 of the Act of 1939, the word "convert" is stated to include a change of user, whether or not involving any structural alteration.

Timber By-laws

DATE AND SCOPE OF BY-LAWS. These by-laws came into force on the same date as the General Building By-laws, namely 1st January, 1938. They also are made under the London Building Act (Amendment) Act, 1935, and the Council has power under Section 9 of that Act to modify or waive any requirement. The by-laws are stated to apply to the use of timber in the construction and conversion of buildings, and affect the carrying out of every form of timber construction in buildings.

The by-laws are sub-divided as follows:—A portion containing definitions, four sections and a schedule. Section 1 contains general requirements; Section 2 deals with calculated construction; Section 3 contains Tables and gives rules for their use whereby, when the length (the span) and the breadth (the thickness) of a rafter, purlin, joist or main beam are known, it is possible to determine either the depth or the spacing. Section 4 contains general administrative requirements, and the Schedule contains rules for the grading of timber.

Section 1. The by-laws recognize two classes of timber: non-graded and graded. The requirements for non-graded timber are given in the first paragraph of By-law 3 as follows—

Timber shall be well cut and free from warp, wind or other deformation and from signs of rot, worm and beetle, and shall not contain large, loose or dead knots, checks, splits or other defects to such an extent or so situated in the piece as to render it insufficient in strength or stiffness for its functions in the work, and no timber shall be used which, in the opinion of the district surveyor, is so inferior in quality or condition as not to be suitable for its purpose. Timber, when used, shall be well-seasoned and shall be deemed not to be so if, when tested in the manner described in the Appendix to the British Standard Specification numbered 585—1934, it shows a moisture content exceeding 22 per cent

Graded timber is referred to in the second paragraph of By-law 3—

Provided always that graded timber designated in these by-laws "Grade 1200 lb. *f*." shall be Douglas fir (*Pseudotsuga Douglasii*) or long-leaved pitch pine (*Pinus palustris*) and shall, in addition to any other requirements of these by-laws, comply with the requirements of the Schedule to these by-laws.

The timber Douglas fir is that which is also known, according to the district from which it is obtained, as either Oregon pine, or British Columbian pine.

By-law 4 requires that every rafter, purlin, joist and binder shall have a breadth of not less than $1\frac{3}{4}$ in.

Section 2: Calculated Construction. A list of superimposed loads on, respectively, joists and main beams (termed binders) is given in Table I (not reproduced). This is similar as regards the main beams to the second column of Table I of the General Building By-laws. On comparing the first column of the two tables—slabs in one case and joists in the other—it will be seen that in the Table in the Timber By-laws the loading given is, for some reason, less on residential floors and more on floors of ground floor offices, shops, etc. The loads on roofs are similar in both sets of by-laws.

The maximum stresses in the two kinds of timber are given in Table II as shown on page 1687.

The stresses given in Table II are applicable to posts with a slenderless ratio not exceeding 10. When this ratio is exceeded, the limits of stress are those given in Table III.

By By-law 9 the slenderness ratio of a post is not to exceed 40.

Ceiling joists if calculated are required by By-law 7 to withstand a load of 25 lbs. per sq. ft. without deflecting more than 1-360th of their length.

Section 3: Use of Tables. This Section contains two Tables (not reproduced) from which, by following the rules given in By-law 18, either the depth or the spacing of a rafter, purlin, joist or beam may be determined. Table IV is for non-graded timber and Table V for graded timber. Both the Tables are based on the loading given in Table I, and the stresses in Table II. In using the Tables, the length of a timber is to be taken as the clear span between supports, and the spacing as the clear distance between two rafters, joists, etc., both, of course, in the same unit of measurement, which in all ordinary cases will be an inch unit.

It may perhaps help in appreciating the make-up of the Tables if the "spacing factors" given are considered as being the spacing necessary to carry the dead load, together with the superimposed loads given in Table I, within the limits of stress given in Table II, for timbers having a breadth of 1 in. This is, of course, a purely hypothetical case, as a timber of such little breadth would twist under the load, and moreover, as has already been stated, the use of a timber of less breadth than $1\frac{3}{4}$ in. is not permissible under the by-laws.

The use of the Tables will be found in practice to be generally restricted, in the case of new buildings to the three columns on the left-hand of the Table; for few new office buildings, workshops, factories, etc., in London are now built with wooden floors. In using the Tables the spacing given should not be adopted without due regard to the rules of good practice. The spacing of rafters, for instance, should not be so great that it cannot be spanned safely by the roof boarding or battens, and the spacing of ceiling joists should not be such that the laths carrying a plaster ceiling will deflect and crack the ceiling. In the case of the joists of flat roofs and of floor joists, the spacing should not be such as to affect the safe bearing capacity of the boarding; in this connection it is to be noted that in work under Section 2, it is provided in

TABLE II

Nature of Stress	*Maximum stress in lbs. per square inch* Non-graded	Grade 1200 *lb. f.*
Extreme fibre stress in bending	800	1,200
Shear stress in the direction of the grain	90	100
Compression perpendicular to the grain	165	325
Compression in the direction of the grain in posts and struts having a slenderness ratio not exceeding 10	800	1,000
Tension in the direction of the grain	800	1,200
Modulus of elasticity	1,200,000	1,600,000

TABLE III

Slenderness ratio	*Maximum pressure in lbs. per square inch* Non-graded	Grade 1200 *lb. f.*
Exceeding 10 but not exceeding 12	785	985
,, 12 ,, ,, 14	775	970
,, 14 ,, ,, 16	755	950
,, 16 ,, ,, 18	725	920
,, 18 ,, ,, 20	690	875
,, 20 ,, ,, 22	635	820
,, 22 ,, ,, 24	565	745
,, 24 ,, ,, 26	485	650
,, 26 ,, ,, 28	420	600
,, 28 ,, ,, 30	365	485
,, 30 ,, ,, 32	320	430
,, 32 ,, ,, 34	285	380
,, 34 ,, ,, 36	255	340
,, 36 ,, ,, 38	225	300
,, 38 ,, ,, 40	205	275

By-law 7 that in calculating boarding a superimposed load of 200 lbs. per sq. ft. is to be taken, and in work under Section 3, it is provided in By-laws 16 and 17 that boarding is not to be of less finished thickness than ⅝ in., and that the span of boarding between joists is not to exceed 24 times the thickness of the boarding.

It may already have been noticed that, in calculating the joists for a flat roof, the superimposed load to be taken exceeds that for a residential floor by 10 lbs. per sq. ft.; the closer spacing thereby involved is evident from a glance at the Tables.

The use of Tables IV and V is, of course, restricted to roofs and floors of ordinary weight. They must not be used for roofs carrying a heavy roof-covering such as "stone slates," nor for pugged floors; in such cases the sizes and spacing of the timbers must be determined by calculations under Section 2. The Tables apply, of course, to beams supported at each end; cantilever construction, when determined from the Tables, must be regulated by the rules in By-law 19.

Section 4. This deals principally with administration. By-law 20 contains requirements in regard to the conversion of buildings which are similar to those of By-law 152 of the General Building By-laws.

SCHEDULE. This contains grading rules for the higher quality timber, termed "Grade 1200 lb. *f*." timber. Among these rules there are some simple ones which can be easily remembered, such as the rules that timber is to have not less than four annual rings to the inch, measured radially, that knots are to be sound and free from rot, and that sapwood is to be only slightly discoloured.

DRAINAGE BY-LAWS

Administration. These by-laws have been made by the County Council under the Metropolis Management Act, 1855, and the Metropolis Management Acts Amendment (By-laws) Act, 1899. They are administered by the Borough Councils and do not apply in the City.

Scope. The by-laws apply to surface water drainage, and to drainage from soil fitments and waste-water fitments, which are defined as follows—

"Soil fitment" means a watercloset, slop sink, or a urinal.

"Waste-water fitment" means a bath, lavatory basin, bidet, or a sink other than a slop sink.

Surface Water Drains. No minimum diameter is prescribed. Drains of this type may in certain specified circumstances have untrapped gullies.

Soil Drains. These may be of stoneware, cast iron, or other equally suitable material, not less than 4 in. in diameter, of the thickness and with the arrangements for jointing given in the Schedule to the by-laws. By-law 5 deals in detail with soil drains. They are to be laid with a suitable fall, and are not to be within or under a building, except in a case where any other situation is impracticable. Stoneware drains outside a building are to be laid on a bed of concrete 6 in. thick, projecting 6 in. on each side, and benched up to the level of the centre of the pipe; stoneware drains inside a building are to be laid on a similar bed of concrete and be encased in concrete 6 in. thick. Cast-iron drains in any position below ground are to be on a bed of concrete, benched up, as required for stoneware drains; where cast-iron drains are above ground, they may be carried at each joint on piers.

MEANS OF ACCESS. Drains are to be provided with adequate means of access, with all necessary fitted covers; where access is arranged in a building, a screwed or bolted air-tight cover is to be provided.

Trapping and Ventilation of Drains. The requirements of By-law 5 as to the trapping of inlets to soil drains or soil pipes, by means of fitments or gulleys, are as follows—

(12) *Inlets to drains to be trapped.*—Every inlet, other than a ventilating pipe, to such drain shall be properly trapped by a suitable and efficient trap, and such trap shall be formed and fixed so as to be capable of maintaining a water seal of—

(*a*) Two inches where such inlet has an internal diameter of not less than three inches.

(*b*) Three inches where such inlet has an internal diameter of less than three inches.

The Borough Council are empowered to require an intercepting trap between the drain and the sewer whenever they think fit; when no such trap is provided any drain within or under a building is to be of cast iron. Drains are required to be ventilated by means of two pipes if an intercepting trap is provided, and by one pipe if there is no interceptor. A ventilating pipe is to be of the material and diameter prescribed for soil pipes and is to be carried up vertically to such a height and position as to prevent there being any nuisance from foul air.

Soil Pipes. These are dealt with in By-laws 6 and 7. They are to be of lead, copper, cast iron, wrought iron, or other equally suitable material, and are to have an internal diameter

of not less than 3 in. A soil pipe is to be carried up in a similar manner to a ventilating pipe. The thickness and weight of pipes are given in the Schedule to the by-laws, and the methods of jointing are given in By-laws 6 and 7.

Waste Pipes. These, taking the discharge from slop sinks, urinals, and from waste-water fitments, are required by By-laws 8 and 10 to be formed of similar materials to soil pipes, except that a pipe from a waste-water fitment which discharges into or over a gulley may be of stoneware. The minimum diameters of waste pipes are 3 in. from a slop sink and a urinal with three or more stalls, 2 in. from a two-stall urinal, 1½ in. from a one-stall urinal, and 1¼ in. from a waste-water fitment. Where the diameter of a waste pipe is less than 1½ in. the pipe and trap are to be of non-ferrous metal. Waste pipes from slop sinks and urinals are to discharge into a drain without the interposition of a trap, or into an adjoining soil pipe. Waste pipes from waste-water fitments may be kept separate from the pipes of soil fitments, discharging in such case over or into a gulley, (the two pipe system) or they may be arranged as part of the soil system (the one pipe system). Where the two pipe system is adopted, the practice of arranging the waste pipe to discharge into the gulley below the grating, of course, above the level of the water-seal, is common in London, and is to be recommended. The discharging of a waste pipe into a rainwater head, at one time a frequent practice in the case of bath wastes from upper floors, is prohibited.

All waste pipes are to be trapped immediately beneath the fitment, except that branch wastes from a range of urinals, baths, or lavatory basins, may discharge direct into an open channel of glazed stoneware provided with an efficient trap. The depth of seal of a trap to a slop sink or urinal must be in accordance with that, already mentioned, in By-law 5 for inlets to soil drains. The depth of seal of a trap to a waste-water fitment depends on whether the arrangement adopted is the two pipe system or the one pipe system. In the former case the minimum depth of seal is 1½ in., whereas in the case of the one pipe system the depth of seal must be in accordance with By-law 5.

Where a waste pipe is connected with two or more fitments on different storeys it must be carried up, for ventilation purposes, in a similar manner to a soil pipe.

Ventilation of Traps. This subject is dealt with in By-laws 9 and 10. Ventilation is required, in order to prevent syphonage, in all cases where two fitments are arranged in connection with one another.

DEPOSIT OF PLANS AND GIVING OF NOTICES. These subjects are dealt with in By-law 14.

By-laws Regarding Waterclosets, Etc.

Administration. By-laws dealing with waterclosets, urinals, earthclosets, privies and cesspools, made by the County Council under the now repealed Public Health (London) Act, 1891, and the L.C.C. (General Powers) Act, 1928, are still in force. Such by-laws are administered by the Borough Councils and do not apply in the City.

Rules as to Waterclosets. These are given in detail in By-law 2. There are the general rules that a watercloset shall be so situated that at least one of its sides is an external wall abutting either on a street or on an open space not less than 100 sq. ft. in area, and that a window not less than 2 sq. ft. in area shall be formed in the external wall. There are, however, several provisos to meet the special difficulties encountered in a closely built-up area, and these should be carefully studied, it being noted that the minimum open space is reduced to 40 sq. ft., that in certain circumstances the open space may be at the roof level of the watercloset, and that the provision of mechanical ventilation is permissible in a difficult case. There is a further requirement that a watercloset is not to be entered directly from a room used for habitation, for any kind of work, or for the manufacture, storage or sale of food or drink. A watercloset, however, used exclusively with a bedroom or dressing-room may be entered directly from such room. Various detailed rules are given regarding the construction of watercloset enclosures, etc.

By-law 7 requires that one closet is to be provided for each twelve inmates of a building.

Urinals and Earthclosets. These are dealt with in By-laws 3 to 6. Urinals, as regards position, lighting and enclosures, etc., must comply with the requirements for waterclosets. An earthcloset must have two external walls, and must be entered from the external air.

City Drainage and Sanitary Requirements. These consist of Regulations for drainage, and By-laws for soil, ventilation and waste pipes, slop sinks, urinals, waterclosets, and various other fittings. While similar in many respects to the general London by-laws, the City requirements differ in some points of detail.

Chapter VIII—ACTS OF GENERAL APPLICATION

Town Planning Acts.

Scope of Requirements. The requirements dealt with in the preceding chapters are largely restricted to a particular street or building, without much reference to its relationship with other streets or buildings. Early in the present century it came to be realized that the requirements ought to be extended to control, to a reasonable extent, the relationship of a new street with other streets, and of a new building with other buildings. The first Act to deal with things from this standpoint was the Housing, Town Planning, Etc., Act, 1909, which, while dealing principally with housing, contained provisions which enabled a local authority to prepare a plan for land in course of development or likely to be used for building purposes. This was followed by the Town Planning Act, 1919, which gave power to local authorities to act together in preparing a regional plan, and made it compulsory, within a limit of time, subsequently extended, for boroughs and urban districts with a population over 20,000 to prepare a scheme. The powers of authorities were further increased and the law on town planning consolidated by the Town Planning Act, 1925. Then followed the Town and Country Planning Act, 1932, again a consolidating Act, which extended the powers of authorities "to any land whether there are or are not buildings thereon." This Act, is still the main statute dealing with town planning, but it has been in some important respects amended by the Town and Country Planning (Interim Development) Act, 1943, and the two Acts must be read together.

The scope of a further Act, the Town and Country Planning Act, 1944, is restricted to the acquisition of land and the control of its development by planning authorities.

All the recent Town Planning Acts have contained references to the powers of "the Minister," and until 1943, "the Minister" was the Minister of Health. In that year, by a special Act, a new Government Department was created, and this term, in the Acts and regulations dealing with planning, was defined to mean the Minister of Town and Country Planning.

Town and Country Planning Act, 1932.

AUTHORITIES. The authority for a town planning scheme in a district outside London will usually be the local Borough Council, Urban District Council or Rural District Council. But in some districts the authority may be a Joint Committee constituted under Section 3 of the Act of 1932, or it may be the County Council, for it is provided in Section 2 of that Act that the council of any non-county borough, urban or rural district, may by agreement relinquish any of their powers in favour of the County Council. In London there are two authorities: in the City of London the City Corporation, and in the rest of the County the London County Council.

PROCEDURE IN PREPARATION OF SCHEME. The procedure to be adopted in preparing a town planning scheme is laid down in Sections 6 to 9 of the Act of 1932. The first step is the passing of a resolution by the authority that a scheme is to be prepared. This is to be followed by a number of steps, including the service of notices on owners and occupiers, the preparation of a draft scheme and its public advertisement, the consideration of objections to the draft scheme, the preparation of the final scheme and its submission to and approval by the Minister. It will be appreciated that the preparation of a scheme, and the carrying it through to the final stage, involve work over a period of years.

Although under the Town Planning Act, 1919, the authorities for all boroughs and urban districts having a population of over 20,000 were required to prepare a scheme by 1926, this date was from time to time extended, and, on the outbreak of war, there were a large number of districts in which no steps had been taken to prepare a scheme, and in which consequently the local authority had no definite town-planning powers. This state of affairs was changed by Section 1 of the Town and Country Planning (Interim Development) Act, 1943, which provided that three months after the commencement of the Act all land not the subject of a town planning scheme was subject to a resolution to prepare or adopt a scheme, which resolution was to be deemed to have been passed by the local authority and approved by

the Minister. It was further provided that no service of notice on owners and occupiers was necessary under this procedure. The position now is that all land covered by Town and Country Planning Acts, namely the whole of Great Britain and Northern Ireland, is either subject to an approved scheme or to a resolution to prepare a scheme.

CONTENTS OF A SCHEME. Sections 11 and 12 of the Act of 1932 regulate the scope of a town planning scheme. Section 11 states that every scheme shall define the area to which it applies, shall specify the authority for enforcing it, and shall contain such provisions as are necessary for regulating the development of land, and in particular the matters mentioned in the Second Schedule to the Act. The principal of these matters are stated to be: streets and roads, including the stopping up or diversion of existing highways; buildings; open spaces both private and public; the reservation of sites for certain purposes; the control of the deposit of waste materials and refuse; sewerage, drainage and sewage disposal; lighting; water supply; and the extinction or variation of private rights of way or other easements.

The subject of the control of buildings is dealt with in detail in Section 12. The first part of this section is as follows:—

(1) The provisions to be inserted in a scheme with respect to buildings and building operations may include provisions—

(*a*) prescribing the space about buildings

(*b*) limiting the number of buildings

(*c*) regulating or enabling the responsible authority to regulate the size, height, design and external appearance of buildings

(*d*) imposing restrictions upon the manner in which buildings may be used, including, in the case of dwelling-houses, the letting thereof, in separate tenements; and

(*e*) prohibiting building operations, or regulating such operations in respect of matters other than those specified in this sub-section.

A proviso then follows to the effect that when a scheme enables an authority to regulate the design or external appearance of buildings, the scheme must provide that any person aggrieved shall have the right of appeal either to a court of summary jurisdiction or to a specially constituted tribunal.

As regards to practical application of the law, it is usual in an approved scheme for the land of the local authority to be "zoned," as it is termed, for buildings of different use, a certain area being allocated for dwelling-houses only, a certain area for business premises only, other areas for respectively light and heavy industries etc. In the case of dwelling-houses the density, or number of houses per acre is specified; also, among various other matters, the open space about buildings and the height of buildings is usually limited, and, of course, the lay-out and width of all new streets must be in accordance with the scheme.

Sections 18 to 24 deal with the questions of compensation and betterment, Section 18 setting out the general rights of owners in regard to compensation, and Sections 19 and 20 dealing with the exclusion or limitation of compensation in certain cases. In this connection the question whether a building or work is an existing building or "existing work" is of great importance. These terms, together with the term "existing use," are defined in Section 53, and it should be noted that "existing building" and "existing work" are stated to include a building or work "erected, constructed or carried out in accordance with the terms of an interim development order, whether made under this Act or any Act repealed by this Act, or of permission granted under such an order."

Town and Country Planning (Interim Development) Act, 1943. When the Town and Country Planning Act, 1932, was being drafted it was realized that, after the passing of a resolution to prepare a scheme in a particular area, there was a risk of development being much retarded if the owners of property in the area were left without any knowledge of what type of development would be likely to conform to the scheme. It was, therefore, provided in Section 10 of the Act, that the Minister should make a General Order with respect to the "interim development" of land in any area, the term being defined as meaning development between the date on which the resolution took effect and the date of the coming into operation of the scheme. An Order was consequently made by the Minister in 1933, but this was rescinded in 1944, and replaced in that year and each subsequent year by an Order made under the Town and Country Planning (Interim Development) Act, 1943.

To understand the regulations regarding interim development it is necessary to read Section 10 of the Act of 1932, together with the whole of the Act of 1943, and the present Order, known as the Town and Country Planning (General Interim Development) Order, 1946. Sub-section 3 of Section 10 of the Act of 1932, provides that where an authority receives an application for interim

development it may grant it unconditionally or subject to conditions or it may refuse it; Sub-section 5 gives an applicant who is aggrieved by a refusal or by the imposition of conditions the right within twenty-eight days to appeal to the Minister. Under Section 2 of the Act of 1943, a local authority is able to postpone the consideration of an application, but the applicant has the right within twenty-eight days to appeal to a court of summary jurisdiction. In Sub-section 3 of Section 10 of the Act of 1932, there is a proviso giving a list of cases in which an authority is not entitled to refuse an application for interim development, but this proviso was repealed by Section 2 of the Act of 1943, and to ascertain what development is permissible without specific approval, and the limitations of authorities in refusing permission to develop, one has to refer to Articles 4 to 8 of the Interim Development Order of 1946. Article 4 of the Order sets out several classes of development which, subject to the subsequent provisions of the Order, may be undertaken without the permission of the authority; the principal of these are as follows—

Class III. The rebuilding, restoration or replacement of buildings and plant which have sustained war damage, except operations involving an increase in the cubic content of any building as it existed immediately before the occurrence of the damage, or a material alteration of the exterior of any such building.

Class IV. The carrying out of alterations to existing buildings and of operations required for the maintenance of existing buildings, except alterations affecting the exterior of, or required in connection with an alteration of the use of, any building

This freedom from control, however, may not always exist, as it is provided in Article 5 that an interim development authority, with the consent of the Minister, may direct that the foregoing provisions of Article 4 shall not apply in a particular area. But it would appear, nevertheless, that a figure of cost is to be mentioned in the "direction," below which it would be permissible to carry out certain works. Articles 6, 7 and 8 deal with the extent and limitation of the powers of an interim development authority in certain special cases, and there appears to be some conflict between the provisions of Article 8 and the already-mentioned provisions of Article 4.

Under Section 2 (3) of the Act of 1943 an application for consent to development is deemed to be refused, if after the expiration of two months it has not been approved or its consideration postponed.

ADMINISTRATION OF INTERIM DEVELOPMENT. Article 11 of the Interim Development Order, 1946, ensures the enforcement of the law in regard to town planning by providing that where the interim development authority is also the local authority to whom the plans of streets or buildings are required to be submitted under any by-laws or local Acts, which is, of course, the normal case, such submission of plans is deemed to constitute an application for interim development, and must be dealt with accordingly.

EXAMPLE OF DRAFT SCHEME. As an indication of the kind of control proposed by the London County Council, the Draft Scheme prepared by the Council for Area IV (South-West), comprising the Metropolitan boroughs of Battersea and Wandsworth, an area part residential and part industrial, may be consulted. A copy of this Draft Scheme may be obtained, price 1s., either directly or through a bookseller, from P. S. King & Son, Ltd., 14 Great Smith Street, Westminster, S.W.1, agents for the publications of the Council. The headings of the Scheme are as follows—

Part I. General.
Part II. Reservation of Lands.
Part III. Streets and Building Lines.
Part IV. Building Restrictions and Use of Land.
Part V. General Amenity and Convenience.
Part VI. Maintenance, use, alteration, extension, and replacement of Existing Buildings, and continuance of Existing Use of Land.
Part VII. Plans, Approvals, Appeals.
Part VIII. Miscellaneous.

Part IV deals with the following matters: Erection and use of buildings and use of land; density; space about buildings; height of buildings; external appearance of buildings; and the siting of buildings.

It should be appreciated that this Draft Scheme, in common with all draft schemes, represents only the proposals of the development authority, and it does not follow that every proposal will be approved without modification by the Minister of the Town and Country Planning.

Effect of Acts on Other Legislation. It should, of course, be realized that the requirements of the Town Planning Acts are in addition to and not in substitution for other legislation. It follows, therefore, that proposed compliance with certain requirements of by-laws or local Acts in such matters as width of streets, height of buildings,

etc., may not be considered to warrant approval under town planning, particularly in a case where there is an approved scheme in force.

Town and Country Planning Act, 1944. This Act gives planning authorities powers of compulsory purchase in areas of extensive war damage, and of bad lay-out and obsolete development. It contains detailed requirements as to procedure, compensation, and control of development.

The Town and Country Planning Act, 1932, applies throughout Great Britain, but the two later Acts of 1943 and 1944, apply only in England and Wales, there being special Acts for Scotland and Northern Ireland.

Restriction of Ribbon Development Act, 1935

In 1935, it became to be realized that much undesirable development was proceeding by the erection of lines of buildings as "ribbons" along the sides of main traffic roads. While it was possible for this form of development to be checked under the Town and Country Planning Act in districts with approved schemes, it was appreciated that the preparation and approval of schemes throughout the country would take a considerable time. Having regard, therefore, to the urgency of the matter it was decided to deal with it by means of a special Act: the Restriction of Ribbon Development Act, 1935, which is unamended as regards the execution of permanent work.

RESTRICTION OF RIBBON DEVELOPMENT. Section 1 of the Act empowers a highway authority by resolution to adopt, in the case of any road, certain standard widths specified in the 1st Schedule, which widths vary from 60 ft. to 160 ft. Thereupon it is not lawful, without the consent of the authority, to form any means of access to or from the road, or to erect any building or carry out any works within the limits of the standard width.

Section 2 provides that in the case of all roads which were classified roads on 17th May, 1935, it is not lawful, without the consent of the highway authority, to form any means of access to or from the road, or to erect any building within 220 ft. from the middle of the road. This restriction on the erection of buildings is stated not to apply to a building, other than a dwelling-house, used mainly for agriculture, which term is stated in Section 24 to include horticulture when carried on as a trade or business. A classified road is stated in Section 24 to be a road classified by the Minister of Transport in Class I or Class II under the Ministry of Transport Act, 1919.

Section 7 of the Act of 1935, deals with the exercise by a highway authority of its power to give consent under Sections 1 and 2. It provides that consent to the re-erection, extension, or alteration of a building existing at the commencement of the Act is not to be withheld unless the work is of such a nature that it is comprised in the list of certain works set out in the 3rd Schedule; for these the text of the Schedule should be consulted. Any person aggrieved by a decision of a highway authority under this section has the right of appeal to the Minister of Transport.

Section 6 requires the highway authority to provide plans for public inspection at its offices showing all roads subject to restriction. Section 9 provides that any person whose interest is injuriously affected by the application of Sections 1 and 2 is entitled to compensation.

It will be noted that the authority in the foregoing matters is the highway authority which in rural districts will be the county council; in non-county boroughs and urban districts it may be the borough or urban district council or it may be the county council, according to the arrangements made in each individual case under the Local Government Acts; in county boroughs it will be the borough council.

PREVENTION OF TRAFFIC OBSTRUCTION. Sections 16 and 17, which deal with matters of a different character, not mentioned in the title of the Act, are administered by the local authority, namely the authority charged with the administration of the Public Health Acts and by-laws. It will be appreciated that, in all county boroughs, and in some non-county boroughs and urban districts, the highway authority and the local authority are the same body. Section 16, extends the powers of local authorities as regards the provision of parking places for vehicles. Section 17 has a very important bearing on the erection of certain buildings by private owners. The section provides that when in the case of certain specified classes of buildings, an application is made to the local authority for the approval of the plans of a new building, the authority are empowered, unless they are satisfied that there will be no interference with the traffic in the street, after consultation with the chief officer of police for the district, to require "the provi-

sion and maintenance of such means of entrance and egress, and of such accommodation for the loading or unloading of vehicles, or picking up and setting down of passengers, or the fuelling of vehicles" as they may specify.

The section is stated to apply to the following classes of buildings—

Any building whereof the external or containing walls contain a space of not less than 250,000 cubic feet measured in accordance with directions given by the Minister of Health, and to any place of public resort, refreshment house, station for public service vehicles, petrol filling station, or garage used or to be used in connection with any trade or business.

Any person aggrieved by a decision of a local authority under the section may within 28 days appeal to a court of summary jurisdiction, and there is a right of appeal, against a decision of the court, to quarter sessions.

POSITION IN LONDON. Section 20 provides that, except so far as any provisions of the Act are made applicable by orders made by the Minister of Health, the Act shall not extend to the County of London. The section also enacts that, in the event of an Order being made, it shall provide that the powers are not to be exercised by the County Council without prior consultation with the Ministry of Transport, the local borough council, and, in the City, the City Corporation, and that any appeal by a person aggrieved is to be made to the Tribunal of Appeal, constituted under the London Building Acts. No Order has been made in regard to the portions of the Act that deal directly with ribbon development, but an Order has been made extending the provisions of Section 17 to London, the title of the Order being The Restriction of Ribbon Development (Provision of Means of Entrance and Egress to Buildings) London Order, 1936. The effect of this Order is that, except for the fact that the administrative authority is the County Council and not the local authority, and that the appeal authority is the Tribunal of Appeal under the London Building Acts, the provisions of Section 17 apply in London in the same manner as in the provinces.

Restriction of Ribbon Development (Temporary Development) Act, 1943. This Act enables a highway authority to approve development as a temporary measure under Sections 1 and 2 of the Act of 1935, notwithstanding the refusal of consent to permanent development.

The Restriction of Ribbon Development Acts, except for the special limitation in regard to London, apply throughout Great Britain.

Shops Act, 1934

Section 10 of this Act provides that every part of a shop in which persons are employed shall be properly ventilated and heated, and that in every shop, except one exempted from the requirement, suitable and sufficient sanitary conveniences and washing facilities shall be provided for the use of the persons employed. A shop is exempt from the requirement if the local sanitary authority, whose duty it is to administer this section of the Act, is satisfied that, by reason of restricted accommodation or other special circumstances, the shop should be exempted and gives a certificate accordingly. If a certificate is refused the owner has a right of appeal to the county court.

The Act applies throughout Great Britain.

Housing Act, 1936

Scope. While the greater part of the Act deals with the provision of housing accommodation by local authorities and the powers of such authorities in regard to the prevention of overcrowding and the clearance of insanitary areas, there are certain sections in Part II, which affect the erection of buildings by private owners, and provide for the proper maintenance of existing buildings in private ownership.

PROHIBITION OF BACK-TO-BACK HOUSES. Section 22 prohibits the erection of houses of the back-to-back type, a form of design which was at one time common in many districts, but which is now realized to be unsatisfactory, owing to the lack of cross-ventilation. The section provides that it is unlawful to erect houses of this type to be used as dwellings for the working classes. It is stated, however, that this prohibition "shall not apply to houses abutting on any streets the plans whereof were approved by the local authority before 1st May, 1909, in any borough or district in which on 3rd December, 1909, any local Act or by-laws were in force permitting the erection of back-to-back houses."

INSANITARY HOUSES. Sections 9 to 12 deal with the powers of local authorities in regard to the repair, demolition and closing of insanitary houses. Section 9 provides that where a local authority are satisfied that any house occupied be persons of the working class is in any respects unfit for human habitation they are to serve a notice on the owner, requiring him within a specified time, to execute the works specified in the notice. If the notice is not complied with the local authority has power under Section 10

to do the work and charge the owner with the cost. Sections 11 and 12 deal with the powers of a local authority to require the demolition of an insanitary house and the closing of any part of a house which is unfit for human habitation. Section 15 provides that any person aggrieved by a notice or Order under Part II of the Act may, within 21 days, appeal to the county court.

RELAXATION OF BY-LAWS. Section 138 provides that where new buildings are constructed or new public streets laid out in accordance with plans and specifications approved by the Minister of Health, any provisions of building by-laws that are inconsistent with the approved plans and specifications are not to apply.

The Act applies throughout England and Wales.

FACTORIES ACT, 1937

Scope. This Act comprises fourteen Parts, of which Parts II and III, dealing respectively with health and safety, contain the principal requirements affecting building work. The provisions of the Act are administered in part by the factory inspector, who is a civil servant on the staff of the Home Office, and in part by the "district council" which term is stated in Section 152 to mean the council of a borough or county district in the provinces, and in London, except as regards the fire escape requirements, the City Corporation in the City, and elsewhere the local metropolitan borough council.

Definition of "Factory." The term "factory" is defined in Section 151 as follows—

> Subject to the provisions of this section, the expression "factory" means any premises in which, or within the close or curtilage or precincts of which, persons are employed in manual labour in any process for or incidental to any of the following purposes, namely—
>
> (*a*) the making of any article or of part of any article; or
>
> (*b*) the altering, repairing, ornamenting, finishing, cleaning, or washing, or the breaking up or demolition of any article; or
>
> (*c*) the adapting for sale of any article;
>
> being premises in which, or within the close or curtilage or precincts of which, the work is carried on by way of trade or for purposes of gain and to or over which the employer of the persons employed therein has the right of access or control:

The section also contains a list of premises which are stated, whether or not they come within the scope of the above definition, to be in all cases factories.

GENERAL REQUIREMENTS AS TO HEALTH. These, which are contained in Sections 1 to 6, deal with cleanliness, overcrowding, heating, ventilation, lighting, and the drainage of floors. The requirements dealing with cleanliness are principally those of maintenance. The provisions of Section 2 dealing with over-crowding are to the effect that a factory shall not be so overcrowded as to cause risk of injury to health, and it shall be deemed to be so overcrowded if the amount of cubic space per person is less than 400 cub. ft. This requirement as to cubic space, therefore, governs the design of all new factories. As regards factories in existence at the date of the passing of the Act the section provides that rooms used as workrooms are acceptable with a cubic space of 250 cub. ft. per person for a period of five years, and for a further period of five years if suitable mechanical ventilation is provided.

As regards heating, Section 3 requires that a reasonable temperature shall be maintained in each workroom, and lays down the rule that, where a substantial proportion of the work is done sitting and does not involve serious physical effect, a temperature of less than 60 degrees shall not be deemed, after the first hour, to be a reasonable temperature. Sections 4 and 5 deal with the provision of effective and suitable ventilation and lighting, and Section 6 requires the drainage of floors where any process is carried on of such a wet nature that wet can be removed by drainage.

All the foregoing sections are administered by the factory inspector.

SANITARY CONVENIENCES. Section 7 deals with the provision of sufficient and suitable sanitary conveniences for persons of each sex, in accordance with regulations made by the Home Office. These are termed "The Sanitary Accommodation Regulations, 1938," and are published by H.M. Stationery Office. They deal in detail with the questions of ventilation, screening and approach, and they prescribe a minimum number of conveniences in relation to the number of persons employed. This minimum is one convenience for every 25 females, and in the case of males, where sufficient urinal accommodation is also provided, one convenience for each 25 males up to the first 100, and thereafter one for each 40. Any odd number less than 25 or 40, is to be reckoned as 25 or 40.

This section is administered by the district council.

REQUIREMENTS AS TO SAFETY. The greater part of Part II, namely, Sections 12 to 33, deals with such matters as the fencing of machinery, safety rules in regard to lifts, hoists, and cranes, and in regard to steam boilers, all of which are important from an engineering standpoint. Among these sections is one affecting the construction of buildings, namely Section 25, which is to the effect that all floors, steps, stairs, passages and gangways, are to be of sound construction, properly maintained, and that every staircase is to have a handrail.

MEANS OF ESCAPE. Sections 34 to 37 deal with the important question of means of escape in case of fire. Section 34 provides that every factory to which the section applies shall be certified by the local district council as being provided with such means of escape in case of fire as may reasonably be required in the circumstances of each case. Requirements as to means of escape in case of fire have been in force since the passing of the Factory and Workshops Act, 1901, but such requirements applied only to factories and workshops in which more than 40 persons were employed. The scope of the present requirements is much more extensive, as Section 34 is stated to apply to every factory—

(a) in which more than twenty persons are employed; or

(b) which is being constructed or converted for use as a factory at the date of the passing of this Act, or is constructed or so converted after that date, and in which more than ten persons are employed in the same building on any floor above the ground floor of the building; or

(c) of which the construction has been completed before the passing of this Act and in which more than ten persons are employed in the same building above the first floor of the building or more than twenty feet above the ground level; or

(d) in or under which explosive or highly inflammable materials are stored or used.

The section provides that in the County of London, which includes the City, the administrative authority for fire escape is the London County Council. In all cases where the occupier of a factory considers himself aggrieved by any requirement or by the refusal of a certificate he may, within 21 days, appeal to a court of summary jurisdiction.

The Act applies throughout Great Britain.

Civil Defence Act, 1939

PUBLIC AIR-RAID SHELTERS. This Act, which although now in abeyance, is part of the permanent statute law, deals with the provision of air-raid shelter in areas specified in an Order made by a Secretary of State. It is the duty of local authorities to provide public air-raid shelter. A local authority has power under Section 2 by notice to designate a building or part of a building as being suitable for the construction of an air-raid shelter. Under Section 3 any person having any estate or interest in the building has a right of appeal within 14 days to a Secretary of State against the designation. In a case where the designation is accepted by all interested persons, or, on appeal is confirmed by the Minister, the local authority are entitled to carry out all necessary works for the provision of air-raid shelter, compensation being, of course, payable. On the works being completed it is unlawful under Section 5 for any person to make a structural alteration of the building without the consent of the local authority.

AIR-RAID SHELTER IN FACTORIES AND COMMERCIAL BUILDINGS. The provision of air-raid shelter by private owners is governed by the character of the building and the number of persons occupying it. Section 14 of the Act, imposes the duty on the occupier of any factory premises, and on the owner of a commercial building, of making a report in writing, in the case of factory premises to the factory inspector, and in the case of a commercial building to the local authority, stating what measures are being taken to provide air-raid shelter. In a case where the factory inspector or the local authority are not satisfied that the air-raid shelter is of the required standard, they are empowered by Section 16 to serve a notice requiring shelter of the approved standard to be provided. The term "commercial building" is defined in Section 89 (5) as "a building in which more than 50 persons work, not being—

(a) a building wholly or mainly occupied as a school, college, university, hotel, restaurant, club, place of public entertainment or amusement, hospital or nursing home; or

(b) a building wholly occupied by public utility undertakers for the purpose of their undertaking."

Buildings of the category referred to in (b) are specially dealt with in Part V of the Act.

The provisions of Section 22, whereby an exchequer grant was payable to cover a portion of the cost of providing air-raid shelter in factory premises and commercial buildings, no longer operates, as it was subject to a time limit which has expired.

Section 19 contains provisions whereby the owner of a commercial building may recover all or part of his expenses from his tenants by

an increase of rent over a period not exceeding 10 years. The section deals also with the question of a reduction of rent in a case where the usefulness of the building or portion of the building is impaired by the provision of air-raid shelter, as when the tenants' accommodation is reduced.

AIR-RAID SHELTER IN FLATS. The provision of air-raid shelter in residential flats is compulsory only when more than half of the occupiers require the owner to provide it. Under Section 30 an owner when so required is to prepare a scheme, and is to serve a copy on each tenant. Then, unless more than half the tenants dissent, it is his duty to carry the scheme into effect, and he is entitled to recoup himself for the expense by making an increase in the rents of all the tenants over a period not exceeding 10 years.

CODE FOR SHELTER CONSTRUCTION. A Code for the construction of air-raid shelters was issued in 1939 by the Ministry of Home Security.

POSITION IN EXISTING BUILDINGS. It will be noted that all the foregoing provisions of the Act have reference to existing buildings. The requirements in the great majority of cases were complied with either in 1939 or in the immediately following years. The provisions, therefore, are now principally of interest as regards the carrying out of alterations to buildings in which statutory air-raid shelter has been provided, and as affecting the relationship of landlords and tenants.

AIR-RAID SHELTER, ETC., IN NEW BUILDINGS. Section 33 provides that the Minister may make regulations imposing the following requirements on buildings erected or structurally altered after the coming into force of the regulations—

(*a*) such requirements as to materials and construction as he considers necessary for the purpose of rendering the buildings less vulnerable to air raids;

(*b*) such requirements as he considers necessary as to the provision of air-raid shelter for the persons using or resorting to the buildings.

No such regulations have, however, yet been made.

The Act has applied throughout Great Britain. Under the Civil Defence (Suspension of Powers) Act, 1945, its operation, as regards the provision of air-raid shelter, is suspended.

WAR DAMAGE ACT, 1943

This Act consolidates the legislation contained in previous Acts dealing with war damage, whereby annual contributions over a period of years were required to be paid by all owners of property, and a War Damage Commission was established to regulate the payment of compensation for war-damage to "land," which term is defined in Section 103 of the Act as including any buildings or works situated on, over, or under land, other than plant or machinery.

Payment may take the form of either a "cost of works payment" or a "value payment." The determination of which payment should apply is a valuation matter based on prices and values on the 31st March, 1939. When a case is dealt with by a cost of works payment, the cost is "the proper cost," as defined in Section 123, at the time of the execution of the works, and it may include the cost of employment of an architect, engineer, surveyor, or land agent.

It will normally be to the advantage of an owner to receive a cost of works payment rather than a value payment, and the War Damage Commission has been authorized by the Treasury to make a cost of works payment in respect of certain classes of houses, even where totally destroyed. These classes are stated in the Practice Notes issued by the Commission to be—

(i) Any house built after 31st March, 1914.

(ii) Any house built before 31st March, 1914, where the Commission is satisfied that immediately before the war damage the structure was practically as sound as at the date of building and that the design, layout, and amenities of the house were reasonably equal to those of similar houses built since 1914.

It will be noted from the wording of paragraph (ii) that a war-damaged house, erected many years before 1914, but subsequently modernized, may possibly qualify for a cost of works payment.

The Act appliés throughout Gıeat Britian and Northern Ireland.

The Royal Institute of British Architects

By C. D. Spragg
Secretary to the Royal Institute of British Architects

The Royal Institute of British Architects is a professional society whose Royal Charter states that it is "an Institution for the general advancement of civil architecture and for promoting and facilitating the acquirement of knowledge of the various Arts and Sciences connected therewith." Founded in the year 1834 it has approximately 10,000 Fellows, Associates and Licentiates; 2,500 students and 6,500 probationers. But it is also a federation of architectural bodies covering the whole of the British Empire, having 98 Allied Societies, Chapters and Branches which are represented on its Council. These societies are not branches of the R.I.B.A. but independent architectural bodies, their "alliance" with the R.I.B.A. connoting general sympathy with the aims and objects of the Royal Institute and approval by the central body of their constitution and rules. There are something over 4,000 members of such societies who are not included in the above figures of membership.

Activities. Briefly, the Royal Institute promotes and controls the training of architects, maintains a Code of Professional Conduct, regulates scales of professional charges and salaries, and operates as an exchange for architectural learning through its Library, its Journal, its conferences and exhibitions. It has also created and operates a system of architectural competitions which has long served as a model for architectural competitions throughout the world; it provides facilities for the general public to become acquainted with architectural matters. It runs an employment register for architects and assistants.

The R.I.B.A. speaks and acts for the architectural profession. It is consulted by H.M. Government and by other professional, cultural and learned societies and institutions on all matters relating to architecture, the technique of building and the creation and preservation of amenities.

History. Like many another good British institution, the R.I.B.A. was born in a tavern, when twelve leading British architects met to form an Institute of British Architects. Two years later the first Royal Charter was granted. In 1846 Queen Victoria instituted the Royal Gold Medal for Architecture. In 1851 the R.I.B.A. established the Architects' Benevolent Society as an independent body. In 1866 the prefix "Royal" was added to the title of the Institute. In 1882 entrance to the Associateship by compulsory examination was established. In 1931 it promoted and secured the passing into law of the first Architects' Registration Act. In 1934 (its centenary year) the new headquarters building at 66 Portland Place was opened by King George V. In 1938 the R.I.B.A. was largely instrumental in securing the passage into law of the second Architects' Registration Act which restricts the title "architect" to persons who are on the Register of the Architects' Registration Council; it is now necessary to qualify by examination for admission to the Register, the examinations recognized for this purpose being the Final and Special Final Examinations of the R.I.B.A. and the examinations of the "Recognized Schools of Architecture" which are accepted as carrying exemption from the Institute examinations.

Organization. The Council is elected annually by vote of the members with the addition of elected representatives of the Allied Societies. The Dominion Allied Societies also appoint London representatives to watch their interests. The Council, which meets once a month, appoints a large number of committees which cover every phase of architectural activity. The Board of Architectural Education, with its various committees, establishes, controls and

directs the whole system of architectural education throughout the Empire. It does not itself maintain schools of architecture which are run by universities and by other bodies such as Schools of Art and Technical Colleges and including the Architectural Association, but it sets the standards of architectural competence (which are always steadily rising), recognizing those schools whose diplomas are accepted by the Board as equivalent to the Royal Institute's own final examination or intermediate examination as the case may be. The Board supervises the curricula of recognized schools of architecture and directs the award of the various valuable prizes and studentships offered annually.

The Architectural Science Board's function is to promote the use of science in architecture. It organizes regular lectures and publishes reports on technical matters; it also co-ordinates the activities of over 100 members representing the Royal Institute on the technical committees of the British Standards Institution, etc.

The Practice Committee deals with questions of professional practice and with questions of interpretation which may arise under the Code of Professional Conduct. Infringements of the Code are dealt with by the Council on a report of its Professional Conduct Committee. A member of the R.I.B.A. must not advertise nor offer his services by means of circulars; he must not act as a house agent or auctioneer; he must not give discounts or commissions, nor receive them unless he applies them for the benefit of his client; he must not endeavour to supplant a brother architect, nor seek to obtain work by under-cutting his professional fees; he must invariably act impartially in all disputes between his client and the building contractor, and must interpret the contract conditions with entire fairness between these parties. He can be remunerated only by fees or salary; he cannot be a director, partner or manager of a company connected in any way with building. Failure to observe these canons of professional conduct renders a member liable to reprimand, suspension or expulsion. The Practice Committee also advises the Council on questions of professional charges and similar matters. The scale of charges is accepted in courts of law as being fair remuneration for the services described in it.

The Library has been built up by purchase and collection of books and works of art and is now the finest architectural library in the world; many of its 50,000 books on architecture, technology and the allied arts are rare and valuable. In peace time it regularly takes in more than 150 architectural periodicals from all parts of the world. It is open free to members but accredited persons interested in architecture may also use it on payment of a small fee.

The R.I.B.A. Journal is issued free to all members though non-members may purchase it at 1s. 6d. per copy or subscription of £1 1s. per annum. It covers all Institute activities, records progress in architecture, acquaints members with technical and scientific progress, and with changes in professional practice, law, etc.

Through its conferences, exhibitions and lectures on various aspects of architecture and subjects allied to it, the Royal Institute acts as a clearing house for architectural learning.

Other activities of the Institute are in the charge of such committees as the Housing Committee, the Town and Country Planning Committee, the School Design and Construction Committee, the Public Relations Committee, the Salaried Members' Committee, the Official Architects' Committee and the Competitions Committee. As their names imply, these committees deal with specific items of architectural organization and practice, reporting to the Council.

An important development of the Royal Institute in recent years has been that of supplying the general public and Press with information on architectural matters. The growing interest of the public in such matters as housing and town planning has led to the establishment of a special department to deal with the very large number of inquiries and requests for facilities, particularly with regard to the spread of knowledge of architectural subjects in schools. The Public Relations Committee possesses an index of lecturers, is compiling an index of films of architectural subjects and has a loan collection of mounted photographs for the use of schools, societies, clubs, the Services, etc.

From the foregoing account of its work and activities it will be seen that the R.I.B.A., while safeguarding the professional interests of its members, is concerned in the broadest sense with the welfare of architecture at large, with the spread of education, the promotion of learning and the stimulation of the public interest in good building and planning of kinds which will provide for the comfort and welfare of individuals not less than for the beauty, amenities and efficiency of towns and villages.

The Royal Institution of Chartered Surveyors

By Brigadier A. H. Killick, C.B.E., D.S.O , M.C., M.A. (Oxon)
Secretary of the Institution

Foundation and Growth of the Institution. The business of land, its management, development and valuation began to emerge as a distinct profession in the mid-Victoria era. The ever-increasing momentum of the industrial revolution, and all the developments which were then necessary to provide for a speedily mounting population, called for men of skill to deal with the novel and complex problems which began to arise. Parliament was full to overflowing with private Bills for town improvements, railway, dock and harbour extensions, and the enlargement of municipal boundaries. This era saw the introduction of an entirely new principle, the power to acquire land by compulsion for public improvements and essential public services, thereby creating a need for men skilled in the measurement and valuation of land who, to quote a phrase from the various land acquisition Acts of that time, were "able, practical surveyors."

In such circumstances, professional friendships were formed between surveyors from all parts and, in 1868, the Institution of Surveyors (later to be known successively as the Surveyors' Institution, the Chartered Surveyors' Institution, and the Royal Institution of Chartered Surveyors) was founded with a membership of rather less than 200.

In 1881, when the membership of the Institution was about 500, a Royal Charter of Incorporation was granted by Her Majesty Queen Victoria. A Supplemental Charter was granted in 1921 by His Majesty King George V, who, in the same year, honoured the Institution by accepting office as its Patron. The Royal patronage has been graciously continued by His Majesty King George VI, by whose command the title "Chartered Surveyors' Institution," adopted in 1930, was changed in 1946 to "The Royal Institution of Chartered Surveyors."

By 1918, after fifty years' existence, the membership of the Institution had increased to just under 5,000. Ten years later its membership numbered nearly 7,000. To-day there are over 12,500 members, probationers, and students.

Objects of the Institution. Under the terms of its Royal Charter the Institution was established to secure the advancement and facilitate the acquisition of that knowledge which constitutes the profession of a surveyor, to promote the general interests of the profession and to maintain and extend its usefulness for the public advantage. The profession of surveyor is defined as the art of determining the value of all descriptions of landed and house property, and of the various interests therein; the practice of managing and developing estates; and the science of admeasuring and delineating the physical features of the earth, and of measuring and estimating artificers' work.

The ideals of the Institution were stated at the Opening Meeting in 1868 by an eminent barrister of the day, who was an original Associate of the Institution. He divided those ideals into three main heads, namely: (*a*) intellectual advancement, by promoting a higher standard of education and training for surveyors; (*b*) social elevation, by raising the standard of the profession in the public eye; and (*c*) moral improvement, by fostering the best spirit of professional conduct and practice.

Qualifications for Membership. Examinations as a means of testing the knowledge and qualifications of candidates for membership were first introduced in 1881, the Institution being the first professional society, apart from bodies representing the statutorily regulated professions of law and medicine, to set up an examination system for this purpose.

The professional examinations comprise the

First, Intermediate and Final Examinations, which are divided into four main subdivisions: (i) Land Agency; (ii) Valuation and Estate Management (Urban); (iii) Building and Quantities; and (iv) Mining, candidates selecting the particular subdivision in which they propose to practise.

To test their educational fitness for the professional examinations, candidates who have not passed the School Certificate (or a similar) Examination, are required to pass the Institution's Preliminary Examination (for candidates under 25 years of age) or the Institution's Special (educational) Test for candidates over that age.

To ensure that candidates for the examinations are properly grounded in the practical as well as in the theoretical rudiments of the profession, candidates (other than those in full-time study at recognized places of instruction) are required to show that they are obtaining practical experience in the profession as defined in the Royal Charters of the Institution.

In order to qualify for election to the lower of the two classes of professional membership, i.e. Professional Associate, a candidate must be not less than 21 years of age and must have passed the First, Intermediate and Final Examinations, and must be actually engaged in professional work as a surveyor in a position approved by the Council of the Institution. Holders of the B.A. and B.Sc. degrees in Estate Management, granted respectively by the Universities of Cambridge and London, may be considered for election without further examination provided they can fulfil certain conditions. The higher class is the Fellowship which is obtained after reaching the age of 30 by candidates who, having passed the examinations mentioned above, have completed five years' practice as a principal of a firm, or in a position of equivalent responsibility.

Certain concessions from the above-mentioned rules are made to ex-Service candidates, and to candidates who desire to enter the Institution later in their professional careers, but these concessions are temporary and a term has been set upon their duration.

Status. Evidence that the qualifications indicated by membership of the Institution are publicly recognized is afforded by the references to the Institution by name in numerous Acts of Parliament; by the fact that on most of the Royal Commissions or Departmental Committees, or other public inquiries affecting land and the interests therein, members of the Institution are either invited to serve or are called as witnesses; by the important positions, both in the Government service and in the public service generally (at home and abroad) to which members of the Institution are appointed; and by the number of occasions on which parties in dispute apply to the President of the Institution for the appointment of an arbitrator.

The first occasion on which the Institution was cited in an Act of Parliament was in 1878, only ten years after its foundation, when it was nominated as one of two bodies empowered to report to the Secretary of State upon any new by-laws framed by the Metropolitan Board of Works. The most recent example of statutory citation is in the War Damage (Valuation Appeals) Act, 1945, by which the Lord Chancellor is required to consult the President of the Institution upon the appointment of persons skilled in land valuation to a tribunal for the hearing of appeals from determinations of value made by the War Damage Commission under the War Damage Act, 1943.

Professional Conduct. The fostering of the best spirit of professional conduct and practice is an object which the Institution has kept consistently to the fore, and the work of its Professional Practice Committee is exclusively devoted to that end.

In 1934, rules of professional conduct which until then had largely been unwritten—though enforceable and enforced when occasion arose—were codified and incorporated in the Institution's by-laws, and the consequence of contravention may be reprimand, or temporary or permanent loss of professional qualifications. By the initiative of the Institution, identical rules of conduct were adopted by the professional bodies representing auctioneers and estate agents, with the result that their application extends to-day to well over 20,000 practitioners. At the same time steps wer taken to ensure that the rules were uniformly enforced.

Organization. The membership of the Institution is grouped at home and in the Colonies into thirty-one regional branches, while in South Africa the Chapter of South African Quantity Surveyors is affiliated to the Institution. Each of the branches is administered by an elected Committee, and each in the British Isles is represented on the Council, which is elected annually by ballot of professional membership. The Branch network provides the dual advantage of enabling the Council to obtain timely

and concerted advice of a professional character upon particular problems from all parts of the country, and of facilitating decentralization from headquarters of a desirable measure of administration.

There is a special organization for junior members of the Institution, with facilities for the use of the Library and the receipt of the monthly Journal.

The headquarters of the Institution are situated at 12 Great George Street, Westminster, S.W.1, which were designed by the late Mr. Alfred Waterhouse, R.A., in 1899, and extended by his son, the late Mr. Paul Waterhouse, in 1912. The headquarters of the Scottish Branch of the Institution are established at 7 Manor Place, Edinburgh.

Particulars of the examinations qualifying for membership may be obtained on application to the Secretary.

The Institution of Structural Engineers

By THE SECRETARY OF THE INSTITUTION OF STRUCTURAL ENGINEERS

THE Institution of Structural Engineers was founded in 1908 and incorporated by Royal Charter in 1934.

The activities of the Institution are devoted to the promotion and general advancement of the science and art of structural engineering in any or all of its branches and to the exchange of information and ideas relating thereto amongst the members of the Institution and otherwise. Meetings are held for reading and discussing papers and communications on structural engineering and on subjects related thereto. The administration of the Institution is directed from its central offices at No. 11, Upper Belgrave Street, London, S.W.1, where Meeting Rooms, Library and Members' Common Room are provided.

The Institution has a membership of over 4,600 and has eight branches which serve the following areas in *Great Britain*: Lancashire and Cheshire; the Western Counties; Yorkshire; the Midland Counties; the South Western Counties; South Wales and Monmouthshire; and Scotland. And *Overseas*: the Union of South Africa.

The Institution publishes a monthly Journal, *The Structural Engineer*, which contains the proceedings of the Institution, papers read and discussions conducted at general meetings, contributions from members of the profession and other information of professional interest. A Year Book containing the roll of members with their addresses is issued free to members. The Library of the Institution contains over 3,000 volumes on structural engineering and allied subjects, to which continual additions are being made. Books may be issued to members by post or may be borrowed or consulted personally.

Examinations are held by the Institution twice a year. In connection with these the Andrews Prize is awarded to the most successful candidate in the complete Associate-Membership Examination; the Husband Prize is awarded to the candidate who takes the complete Associate-Membership Examination and obtains the highest marks in the paper on "Structural Engineering Design and Drawing," and the Wallace Prizes are awarded (*a*) to the candidate taking the whole of the Associate-Membership Examination who obtains the highest marks in the paper: "Theory of Structures (Advanced)" and (*b*) to the candidate obtaining the highest number of marks in the complete Graduateship Examination.

Examinations are held in Great Britain at the following centres—

London, Birmingham, Bristol, Manchester, Middlesbrough, Norwich, Edinburgh, and Glasgow,

and overseas on the same dates in July as in Great Britain at centres in India, New Zealand, South Africa and elsewhere, when candidates present themselves.

Technical Committees and Research.

A list of technical committees and of official representatives of the Institution on Government and other committees is given in the Year Book, and a summary of the year's work of the committees is given annually in the Session Report. Through the work of these committees the Institution is constantly in touch with all matters affecting the art and science of structural engineering at home, and through its representatives with the latest research and theories throughout the world.

Reports on many matters of professional importance to members are prepared and published by Committees of the Institution specially appointed for the purpose.

Classes of Membership.

There are eight classes of members in the Institution termed respectively Honorary Members, Honorary Associates, Members, Retired Members, Associates, Associate-Members, Graduates and Students.

Members, Associates and Associate-Members are known as corporate members of the

Institution, and Honorary Members, Retired Members, Honorary Associates, Graduates and Students are known as non-corporate members of the Institution.

Members having occasion for designation as belonging to the Institution may use the following abbreviations, namely: Hon.M.I.Struct.E.; Hon.A.I.Struct.E.; M.I.Struct.E.; M.I.Struct.E. (ret.); A.I.Struct.E.; or A.M.I.Struct.E. respectively.

Members and Associate-Members have the exclusive right by virtue of the Royal Charter to describe themselves as, and to use the title of "Chartered Structural Engineer."

With the exception of the classes of Honorary Member, Member, Honorary Associate and Associate, each candidate for election to membership of any class shall pass such qualifying examination of the Institution as the Council may from time to time determine.

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